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FOREWARD

This report presents the results of one of the projects participating in the military-effect programs of Operation Redwing. Overall information about this and the other military-effect projects can be obtained from WT–1344, the "Summary Report of the Commander, Task Unit 3." This technical summary includes: (1) tables listing each detonation with its yield, type, environment, meteorological conditions, etc.; (2) maps showing shot locations; (3) discussion of results by programs; (4) summaries of objectives, procedures, results, etc., for all projects; and (5) a listing of project reports for the military-effect programs.

ABSTRACT

Results of thermal-radiation measurements, including thermal energy as a function of time, broad spectral band, field of view, photographic data, and irradiance versus time, are reported for Shots Lacrosse, Cherokee, and Zuni.

These data were analyzed to obtain fireball radii versus time, color and power temperatures versus time, and estimated thermal yields. The results are presented together with a brief description of the methods of interpretation used by the authors.

The data from Shots Lacrosse and Zuni (39.7-kt and 3.5-Mt surface bursts, respectively) indicate the possibility of a correlation between thermal output and weapon environment. The thermal yields for these two bursts were about as anticipated.

The results from Cherokee (a 3.8-Mt air burst) could not be accurately analyzed due to the unknown effects of cloud cover. It is estimated that the thermal yield of Cherokee was greater than 30 percent of the total yield and that the peak temperature was in excess of 6,000 K.

Scaling considerations are discussed briefly pending the analysis of data from previous field tests.

PREFACE

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Chapter 1
INTRODUCTION

1.1 OBJECTIVES

The objectives of Project 8.1a were to determine the characteristics of the thermal radiation emitted by three of the nuclear devices detonated at the Eniwetok Proving Ground (EPG) during Operation Redwing. The three devices were a 39.7-kt surface burst, a 3.5-Mt surface burst, and a 3.8-Mt air burst.

More specifically, the objectives were to: (1) accumulate basic thermal data for device yields and burst conditions for which these data were not previously available; (2) extend the existing thermal scaling laws to include a wider range of yields; (3) obtain atmospheric attenuation data applicable to nuclear-weapon situations; and (4) determine the thermal energy input to the material samples exposed by Project 8.2, experimental instruments exposed by Project 8.3, aircraft panels exposed by Project 8.4, and the animals exposed by Project 4.1.

1.2 BACKGROUND AND THEORY

Thermal radiation is an important parameter that must be measured in the field for the evaluation of a nuclear device and its effects. In addition to providing a method for determining some of the characteristics of the device itself, thermal radiation produces gross effects in target materials and is a complicating factor that must be taken into account in conducting many experiments at close range to detonations.

Some of the more-important effects caused by thermal radiation are: ignition of materials, burning of humans, flash blindness, modification of the shock wave, and the weakening of structural materials (such as aircraft skins).

The interpretation of measurements of thermal radiation is a complex problem, since the thermal pulse is a transient phenomenon requiring high-time-response instrumentation, and the experiments are usually complicated by the complex geometries of the field-test situations. As a result, the so-called standard thermal measurements are of two basic types: (1) determination of the input to a specific target at a specific location and (2) determination of the thermal characteristics of the particular nuclear detonation to make it possible to extrapolate the phenomena to other yields.

The thermal input to specific targets and exposed experimental samples is generally determined directly by calorimetric instrumentation at each specific location of interest. Scaling from measurements made at other locations on the same detonation is acceptable under limited circumstances, but scaling of parameters from one shot to another is not presently desirable if accurate predictions are required.

The determination and evaluation of the thermal characteristics of the fireball is made from analysis of calorimetric, photographic, and meteorological measurements. Calorimetric instrumentation is used to measure the thermal radiant energy received as a function of time, field of view of the receiver, and spectral filter. Photographic instrumentation is used to determine the size and shape of the fireball as a function of time, the extent of obscuration by smoke and clouds, and the uniformity of the radiating surface. Meteorological data are used in the determination of atmospheric-attenuation coefficients.

The basic thermal measurements are made by means of an integrating calorimetric system having a time response of approximately 20 msec. A limited number of direct measurements of the thermal irradiance versus time are made with radiometers when the limitations of the instruments with respect to sensitivity, time response, and reliability permit. Photographic measurements are made, in conjunction with the calorimetric measurements, with a 16-mm movie camera.

Thermal measurements made by associated projects are sometimes used, to a limited extent, in the determination of the thermal characteristics of the fireball. Calorimetric and photographic instrumentation, identical to that used at surface stations, is usedfor simultaneous measurements from aircraft. This holds many advantages for direct correlation, since all instrumentation, calibration, and data evaluation are carried out in exactly the same fashion by the same group of investigators. Data from high-time-response bolometers and spectrometers are also taken into consideration when applicable.

Prior to Operation Redwing, the thermal data for devices in the megaton region were extremely limited. Data obtained from Operation Ivy were quite limited in scope, and measurements made on the surface and from the air were in serious disagreement. The ground observations, made by the U.S. Naval Research Laboratory (NRL), showed serious departures from the scaling laws then in use. The airborne observations by the U.S. Naval Radiological Defense Laboratory (NRDL) were questionable when applied to scaling relationships, since there was considerable uncertainty in the position and attitude of the measurement aircraft.

The airborne measurements made by NRDL at Operation Castle (Reference 1) indicated that the pre-Ivy scaling relationships might be nearly valid. However, all of the NRDL measurements during Operation Castle were airborne and all of the events measured were surface bursts. Since device yield, mode of detonation, atmosphere, and method of observation at EPG are all different from those at the Nevada Test Site (NTS), determination of the characteristics of the Castle devices was uncertain, due to the limited scope of the measurements.

Operation Redwing not only provided an opportunity to observe megaton-range bursts from the ground and air simultaneously, but also provided the first opportunity to make close-in ground measurements of the thermal radiant energy from megaton-range devices at relatively high levels of energy.

The prediction of thermal-radiant energies at large distances from the point of detonation is dependent upon the attenuating properties of the atmosphere. Although many experiments have been performed in an attempt to arrive at suitable attenuation coefficients, the experimental conditions have not closely approximated the geometry of the nuclear-weapon situation. Small variations in attenuation coefficients lead to large variations in the thermal energy received at the large distances of interest. Operation Redwing provided an opportunity to determine effective values of attenuation in the actual weapon situation.

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Chapter 2
PROCEDURE

2.1 STATION LAYOUT

Basic measurements were made for three shots from ground installations at relatively close ranges. Calorimetric and photographic instrumentation were mounted as shown in Figure 2.1, which shows 24 thermal instruments and four gun-sight-aiming-point (GSAP) cameras aimed at a common target. Similar assemblies were used at field stations, as in Figure 2.2, and on top of the NRDL trailers, as in Figure 2.3. The locations of the measurements made during each shot are given in Table 2.1.

The instrument layout was identical at all stations and consisted of four GSAP cameras and 24 thermal instruments connected to two independent 12-channel Heiland oscillographic recorders. Instruments were duplicated wherever possible as a precaution against possible recorder failures. For Shots Cherokee and Zuni, the GSAP cameras were linked to the oscillographic recorders so that the time of each frame was recorded simultaneously with the thermal data.

The makeup of a typical measuring station is given in Table 2.2. Column 1 lists the recorder channel, Column 2, the type of measurement, Column 3, the field of view of the measuring instrument, and Column 4, the optical filter used on each instrument. The abbreviations used are TE, for total thermal energy versus time with a 90-degree field of view; FV, for total thermal energy versus time with other than a 90-degree field of view; SP, for total energy versus time transmitted by spectral filters; and RD, for irradiance versus time. The fields of view listed in Column 3 refer to the total angle of the acceptance cone of each instrument. The optical filters are discussed in the next section.

The GSAP cameras had 35-mm and 17-mm lenses and were operated at about 64 and 85 frames/sec. Microfile film was used in combination with neutral density filters to attain the proper exposures.

2.2 INSTRUMENTATION

The instruments used on Channels 1 through 11 were integrating calorimeters of the MK-6F and MK-7F varieties used previously during Operations Castle (Reference 1), Upshot-Knothole (Reference 2), and Teapot (Reference 3). A detailed description may be found in References 2 and 3. The instruments consisted essentially of a blackened copper disk with a thermocouple attached on the back of the disk, designed to integrate incoming thermal radiant energy and to allow determination of the thermal radiant energy received during any time interval whose duration was between 20 msec and the total thermal pulse duration of the detonation. Thus, data from these instruments can be used for a wide variety of applications.

The instrument used on Channel 12 in each recorder was the MK-6F type radiometer, used to give directly the irradiance versus time, to mark time zero, and to indicate the time to minimum and second maximum. A description of these instruments is given in Reference 2.

A field of view of 90 degrees was chosen for most measurements, because of optical and

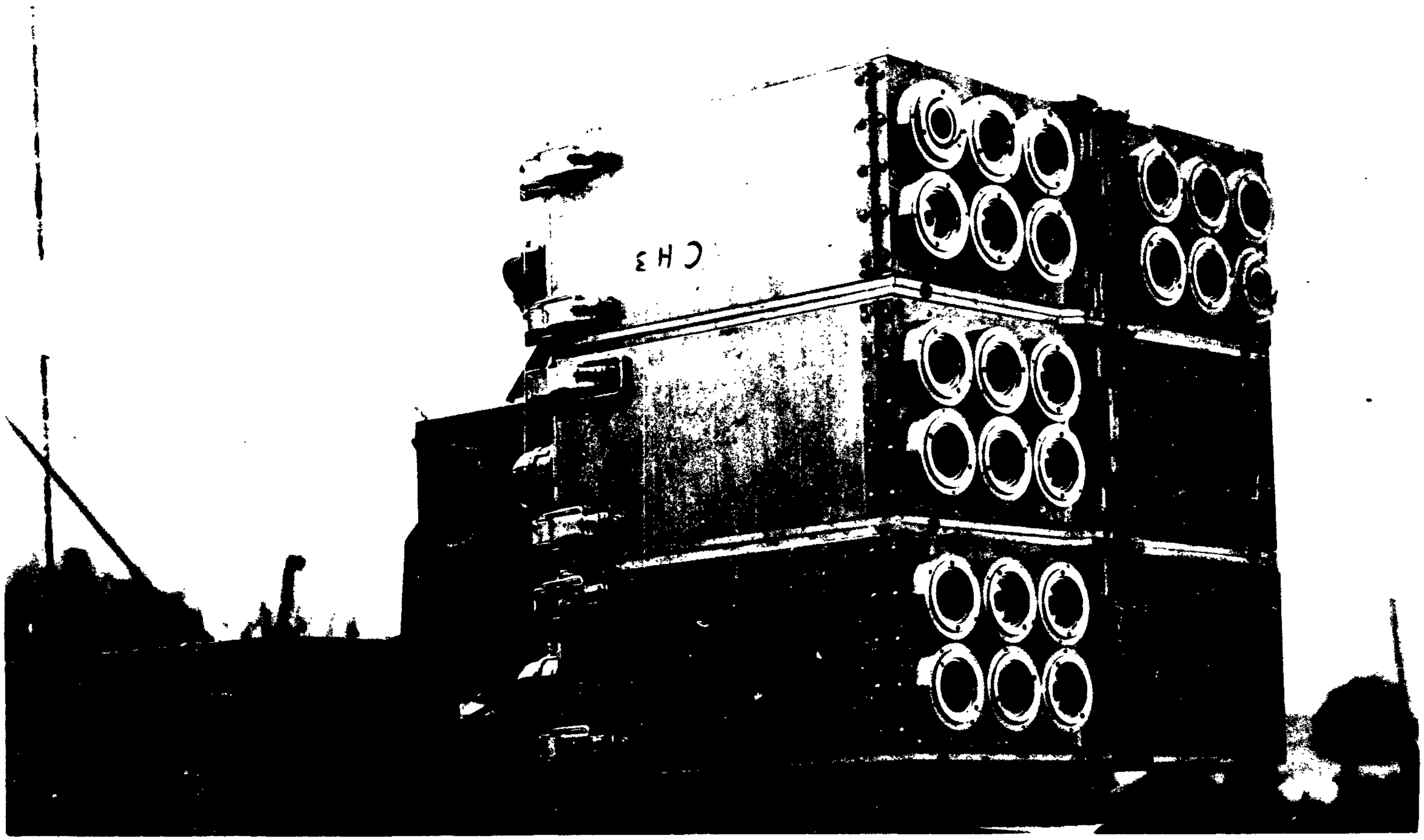


Figure 2.1 Typical thermal-instrumentation mount.

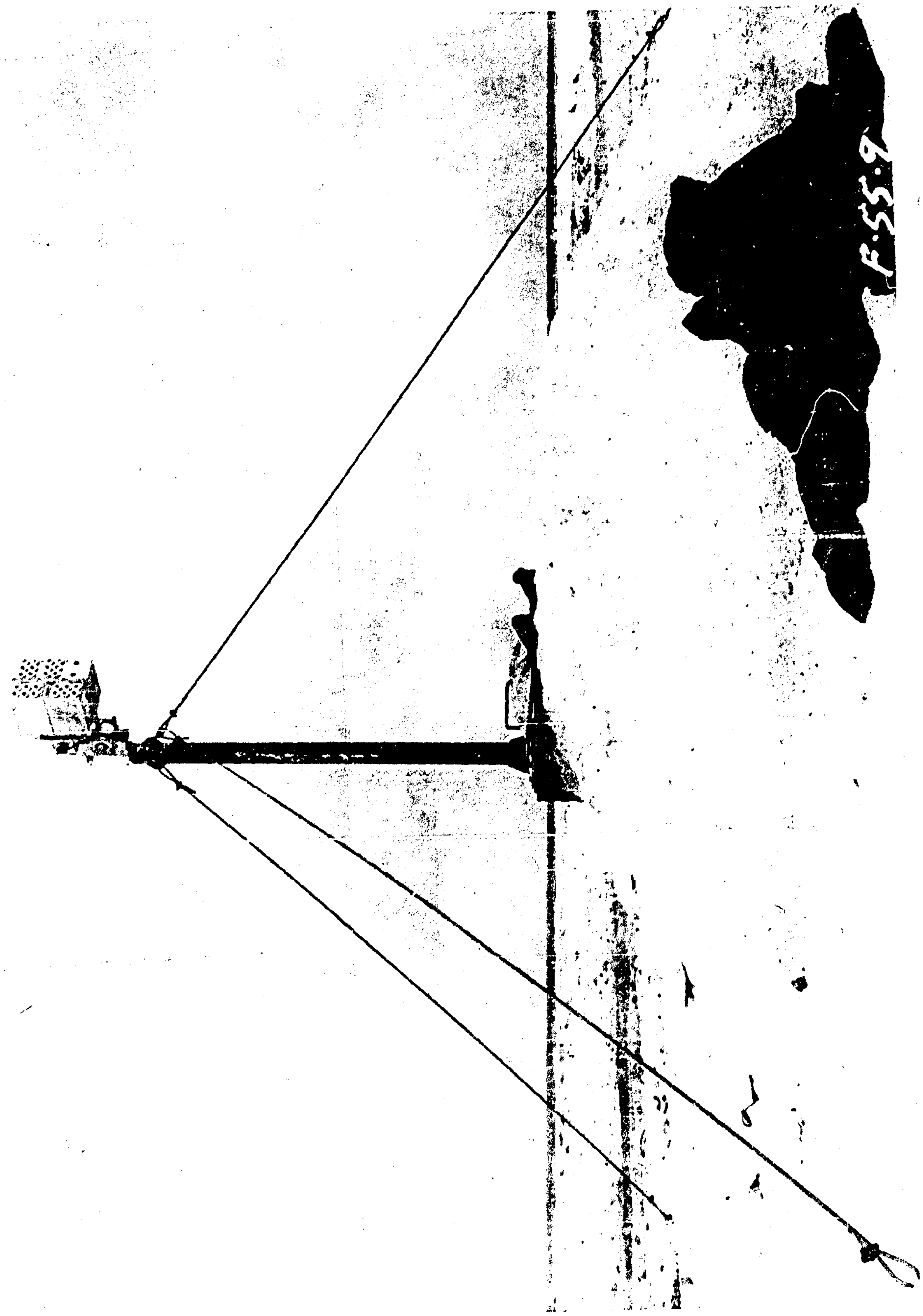


Figure 2.2 Typical field installation.

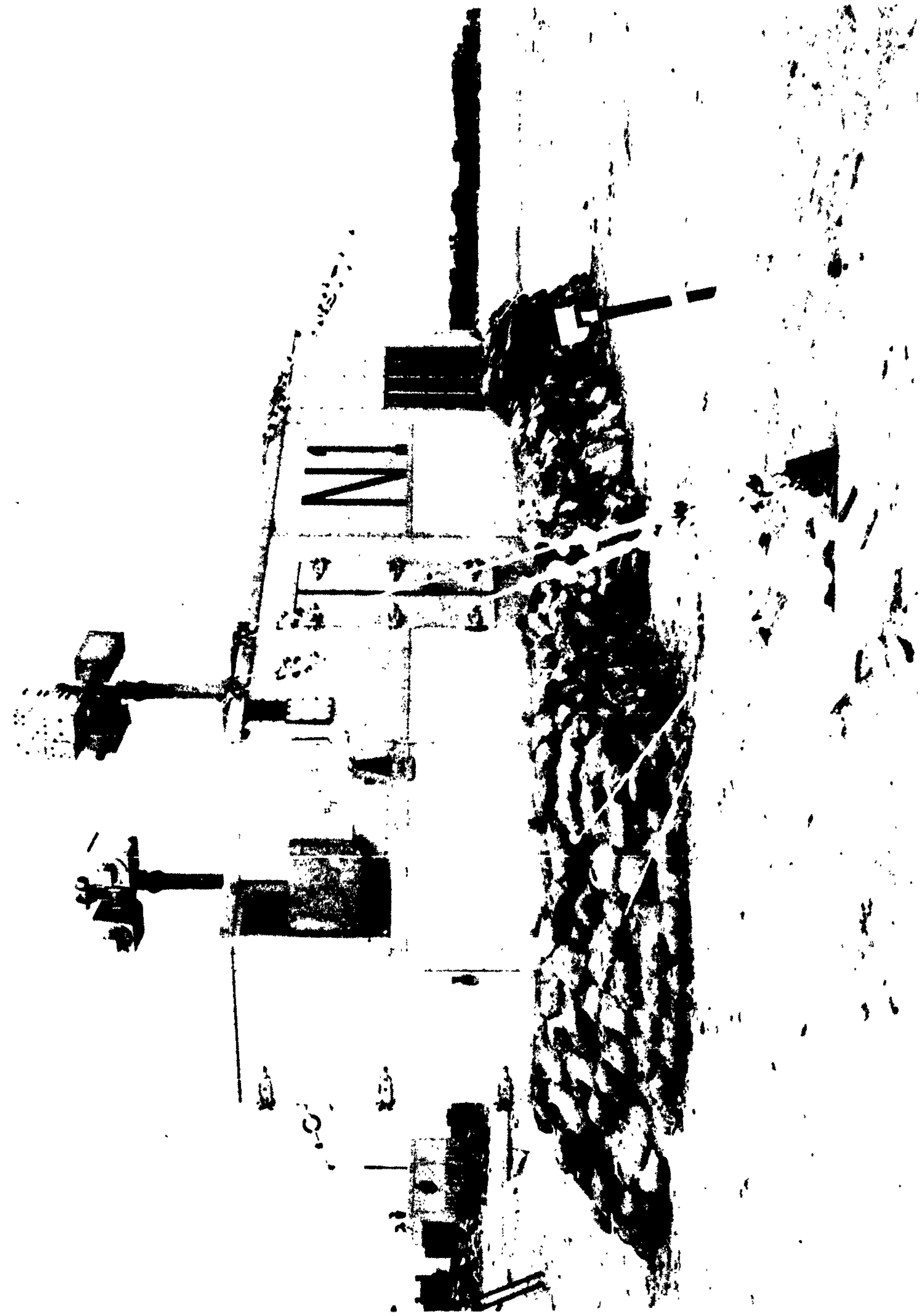


Figure 2.3 Typical trailer installation.

TABLE 2.1 LOCATION OF STATIONS

Shot	Site	Bearing	Slant Range	Height of Instruments Above Sea Level	Alignment Error
			ft	ft	deg
Lacrosse	Yvonne	SE	8,121	30	—
Lacrosse	Wilma	NW	14,392	43	—
Cherokee	Dog	SE	26,380	16	32.5
Cherokee	George	SE	38,837	23	21.5
Cherokee	How	SE	84,406	25	11.2
Zuni	Oboe	E	17,005	20	—
Zuni	William	NW	32,073	50	—
Zuni	Nan	E	68,580	210	—
Zuni	Nan	E	68,580	42	—

TABLE 2.2 MAKEUP OF A MEASURING STATION

1 Channel	2 Function	3 Field of View	4 Filter
		deg	
		Recorder 1	
1	TE	90	Quartz
2	TE	90	Quartz
3	SP	90	3-69
4	SP	90	2-58
5	SP	90	RG-8
6	SP	90	7-56
7	FV	11	Quartz
8	FV	22	Quartz
9	FV	45	Quartz
10	FV	90	Quartz
11	FV	160	Quartz
12	RD	90	Quartz
		Recorder 2	
1	TE	90	Quartz
2	TE	90	Quartz
3	SP	90	0-52
4	SP	90	2-58
5	SP	90	7-56
6	SP	90	7-56+GER
7	FV	11	Quartz
8	FV	22	Quartz
9	FV	45	Quartz
10	FV	90	Quartz
11	FV	160	Quartz
12	RD	90	Quartz

TABLE 2.3 CHARACTERISTICS OF FILTERS

Filter Description	Spectral Region of Transmission	Typical Peak Transmission
	μ	pct
Quartz	0.2 to 4.0	92
0-52	0.36 to 4.0	92
3-69	0.53 to 2.7	90
2-58	0.64 to 2.7	88
7-56	0.95 to 4.0	88
RG-8	0.70 to 2.7	88
7-56+GER	1.50 to 4.0	—

TABLE 2.4 PHOTOGRAPHIC SUMMARY

GSAP Model A cameras have standard 120-degree shutters and were set to run at 64 frames/sec. GSAP Model B cameras have special 30-degree shutters, were set to run at 96 frames/sec, and have time correlation pulse circuits.

Station Number	Slant Range	GSAP Camera Model	Camera Ran	Pct Ran	Roll ID Number
	ft				
Lacrosse				50	
815.01		A	Yes		150101
815.01		A	No		—
815.02		A	Yes		150103
815.02		A	No		—
Cherokee - Not presented due to large drop error.					
Zuni				75	
810.02	32,073	A	Yes		150301
810.02	32,073	A*	Yes		150302
810.02	32,073	B	Yes		150303
810.02	32,073	B	No		—
810.03	17,005	A	No		—
810.03	17,005	A	Yes		150306
813.01†	68,582	A	Yes		150307
813.01†	68,582	A	No		—
813.01†	68,582	B	Yes		150309
813.01†	68,582	B	Yes		150310
813.01‡	68,490	A	Yes		150311
813.01‡	68,490	A	Yes		150312

* 17-mm focal length lens (wide angle)

† On Nan tower

‡ On Nan trailer

mechanical considerations. This field of view is satisfactory for thermal radiant energy and spectral measurements for all but extremely unusual situations.

Filters, as listed in Column 4, Table 2.2, were used to protect the instrument from damage, to control the rate of heat loss, and to restrict the spectral distribution of the thermal radiation reaching the detecting element. The general characteristics of these filters are given in Table 2.3.

Column 1 of Table 2.3 lists the filter designations used in the report. The quartz window was 4-mm fused quartz, polished optically flat to one fringe, with faces parallel to ten fringes. The spectral region of uniform transmission extended in both directions beyond the spectral regions in which appreciable thermal radiation had been detected on previous tests.

The designations 0-52, 3-69, 2-58, and 7-56 denote glass filters obtained from the Corning Glass Works, Corning, New York. The optical quality was similar to the quartz filters, though the thickness was slightly less in some cases.

The RG-8 filter had properties similar to the Corning filters and was manufactured by the Jena Glass Works. It was obtained from Fish-Schurman Corporation, New York.

Wherever a germanium filter (abbreviated GER) was used, a 7-56 was used with it to absorb thermal radiation below 0.95μ and, thus, protect the more fragile germanium.

Column 2 of Table 2.3 lists the region in which the transmission of each filter was relatively uniform. The data from instruments using these filters will be applied in color-temperature and atmospheric-attenuation determinations. Transmission curves for the filters used in color-temperature determinations are given in Reference 3.

2.3 TEST PROCEDURES

The techniques used in calibration of the instruments, gathering data in the field, and reducing data have been used previously (References 1, 2, and 3) and are now well standardized.

A photographic data sheet is presented as Table 2.4.

Chapter 3
RESULTS

The four types of data required for thermal analysis will be presented separately for each shot.

Photographic data are presented in both tabular and pictorial form, since numbers alone cannot be used to adequately describe the complex series of events that take place during a detonation. Pictures were generally chosen to be representative of the situation during each of the time intervals (Reference 3) used in the reporting and analysis of the thermal data. Fireball radii are measured and reported only when the fireball is well defined. Actual exposure times, measured from the first frame, are used in the tabular presentations whenever GSAP Mod B cameras were used. These cameras were modified so that every fifth opening of the 30-degree shutter was recorded on the oscillographic recorders used in the thermal measurements at the same station. Where GSAP Mod A cameras were used, no exact time record is available, and a nominal speed of 60 frames/sec is assumed. Column 4 of Tables 3.1 and 3.5 lists the figure number in this report of those scenes presented in pictorial form.

Calorimetric data, derived from integrating calorimeters, is listed in Tables 3.3, 3.4, 3.7, 3.8, 3.9, 3.10, 3.13, 3.14, and 3.15. The time resolution of the data is 20 msec (50 cycles/sec) and is limited by the time response of the recording system. The data is presented in terms of thermal energy (cal/cm^2) arriving at the blackened receiver disk. Corrections dealing with the measuring properties of the calorimeter, such as calibrations and corrections for heat losses have been applied. Corrections dealing with factors particular to the experimental arrangement, such as alignment error, atmospheric attenuation, fireball geometry, fireball inclusions, environmental factors (such as clouds and reflecting surfaces), and filter transmission are subject to interpretation by the investigator and are discussed in Chapter 4. The data presented in Chapter 3 are thus raw data, which cannot be applied directly, but from which parameters of interest may be computed. Energy values listed indicate the energy received from time zero up until the times listed in Column 1 of each table. Column 2 indicates the scaled times, in terms of the time to second maximum, corresponding to the times listed in Column 1. Identifying information is given at the top of each column to indicate the function, field of view, and filter for each instrument. Explanation of the symbology used will be found in Chapter 2. Although data are listed to four or five significant figures, the probable error in any value is 2 percent. Values should be rounded off after calculations involving the data are completed.

Only those data from instruments showing a measurable galvanometer deflection are reported. Specifically omitted are the Cherokee narrow-field-of-view data, negated by the large drop error, the data from the 7-56+GER filters, since no measurable energy was transmitted and since the filters cracked during the exposure. These unreported data are on file if any future use for them is indicated.

When poor calorimetric results were attained due to instrumental failure, the data has also been omitted from the report, but is also on file. Examples of such failures are when a time-line generator failed and no other means was available to arrive at sufficiently accurate times, or when an oscillograph trace displays obvious irregularities. In cases where times could not be determined for a particular recorder, its data was used to support the data from the companion recorder that worked properly. Such data gives reasonably accurate results for total

TABLE 3.1 LACROSSE PHOTOGRAPHIC DATA, SITE YVONNE

Roll ID Number: 150101
Slant Range: 8,121 feet
Camera: GSAP Serial 42-27204 (Mod A) 120 deg
Speed: Approximately 60 frames/sec

Focal Length: 34.78 mm
Exposure: f:11 with ND-1 filter
Film: Microfile (ASA-1)

Frame	Time	Radius	Figure Number	Frame	Time	Radius	Figure Number
	sec	meter			sec	meter	
1	0.010	114	3.2	17	0.27	274	3.11
2	0.027	172	3.3	24	0.39	—	3.12
3	0.043	167	3.4	36	0.59	—	3.13
4	0.060	180	3.5	50	0.83	—	3.14
5	0.077	196	3.6	88	1.46	—	3.15
6	0.094	206	3.7	143	2.38	—	3.16
7	0.110	218	3.8	180	2.99	—	3.17
9	0.138	236	—	266	4.42	—	3.18
11	0.172	248	3.9	330	5.49	—	3.19
13	0.21	262	3.10				

energy and color temperature, but correlation time-wise with other data cannot be made.

Irradiance versus time was determined by means of foil radiometers, as described in Reference 2, and also from calorimeters. Since the radiometers cannot be relied upon to give

TABLE 3.2 LACROSSE PHOTOGRAPHIC DATA, SITE WILMA

Roll ID Number: 150103
Slant Range: 14,392 feet
Camera: GSAP (Serial Unknown) (Mod A) 120 deg
Speed: Approximately 60 frames/sec

Focal Length: 35 mm (nominal)
Exposure: f:11 with ND-1 filter
Film: Microfile (ASA-1)

Frame	Time	Radius	Figure Number	Frame	Time	Radius	Figure Number
	sec	meter			sec	meter	
1	0.001	48	*	10	0.151	252	*
2	0.018	146		11	0.168	252	
3	0.035	161		12	0.184	252	
4	0.051	179		13	0.201	259	
5	0.068	193		17	0.267	267	
6	0.084	207		24	0.384	280	
7	0.101	214		36	0.584	292	
8	0.118	228		50	0.818	292	
9	0.134	238					

* Negatives not printed for report to avoid unnecessary duplication. Fireball is hemispherical throughout and is not obscured.

reproducible quantitative data, their chief uses are to mark zero time, time to second maximum, and to show any irregularities in the thermal pulse. Irradiance data is presented in graphical form for each station. Continuous curves are used to show radiometer data; horizontal lines to show the average irradiance during each time interval, as determined from the calorimeter records. In all cases the values have been corrected for filter transmission and represent the irradiance incident at the station.

Two radiometers were generally used at each station (see Table 2.2) and were chosen to have differing sensitivities so as to increase the probability of achieving optimum deflection on

TABLE 3.3 LACROSSE CALORIMETER DATA, SITE YVONNE

Time	Scaled Time	FV 160 Q	FV 160 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	FV 45 Q	FV 45 Q
sec	t/t_{2max}										
0.00	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.11	0.5	0.158	0.143	0.164	0.234	0.204	0.213	0.220	0.209	0.127	0.123
0.20	0.9	0.472	0.460	0.463	0.570	0.516	0.524	0.534	0.529	0.423	0.418
0.24	1.1	0.628	0.619	0.626	0.745	0.678	0.694	0.706	0.688	0.578	0.571
0.31	1.4	0.892	0.887	0.883	1.007	0.934	0.963	0.965	0.959	0.817	0.818
0.40	1.8	1.145	1.154	1.141	1.268	1.191	1.229	1.237	1.215	1.056	1.064
0.57	2.6	1.482	1.488	1.481	1.604	1.518	1.559	1.566	1.552	1.366	1.375
0.88	4.0	1.795	1.800	1.788	1.904	1.813	1.864	1.876	1.852	1.647	1.661
1.32	6.0	1.990	1.995	1.989	2.101	2.024	2.052	2.069	2.053	1.817	1.835
2.20	10.0	2.204	2.208	2.194	2.311	2.201	2.251	2.264	2.257	1.980	1.994
3.52	16.0	2.283	2.314	2.302	2.427	2.344	2.369	2.372	2.375	2.048	2.061
6.60	30.0	2.298	2.339	2.330	2.456	2.372	2.384	2.398	2.401	2.064	2.079
∞	∞	2.300	2.383	2.369	2.496	2.416	2.425	2.441	2.442	2.078	2.086

Time	Scaled Time	FV 22 Q	FV 22 Q	FV 11 Q	FV 11 Q	SP 90 0-52	SP 90 3-69	SP 90 2-58	SP 90 2-58	SP 90 7-56	SP 90 7-56
sec	t/t_{2max}										
0.00	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.11	0.5	0.115	0.108	0.096	0.107	0.209	0.175	0.149	0.151	0.056	0.056
0.20	0.9	0.388	0.386	0.344	0.352	0.522	0.438	0.370	0.362	0.141	0.145
0.24	1.1	0.532	0.523	0.468	0.474	0.685	0.569	0.489	0.482	0.188	0.189
0.31	1.4	0.747	0.739	0.648	0.658	0.937	0.788	0.680	0.677	0.273	0.268
0.40	1.8	0.963	0.954	0.828	0.841	1.190	1.010	0.873	0.873	0.347	0.346
0.57	2.6	1.252	1.233	1.050	1.058	1.500	1.289	1.126	1.116	0.463	0.459
0.88	4.0	1.506	1.490	1.239	1.250	1.784	1.559	1.371	1.364	0.589	0.587
1.32	6.0	1.657	1.634	1.351	1.359	1.962	1.729	1.520	1.516	0.701	0.698
2.20	10.0	1.778	1.759	1.415	1.414	2.153	1.912	1.693	1.689	0.845	0.848
3.52	16.0	1.817	1.790	1.419	1.422	2.249	1.994	1.773	1.770	0.929	0.929
6.60	30.0	1.821	1.792	1.421	1.426	2.276	2.015	1.793	1.789	0.952	0.949
∞	∞	1.825	1.798	1.421	1.427	2.315	2.036	1.811	1.798	0.983	0.982

one of the two instruments. In some cases this practice resulted in one of the two instruments having too low an output signal to be measured reliably. Such data is not reported.

3.1 SHOT LACROSSE

Data of adequate quality and quantity were obtained from both stations.

3.1.1 Photographic Data. One of the two cameras at each of the two stations ran successfully. Both of these cameras were GSAP Mod A, which run at about 60 frames/sec and had no time markers. Lack of accurate timing, however, produces little error in fireball diameters on short-time events because the length of individual exposures is too long to permit early time resolution when the growth is rapid, and because the usable portion of the film is of short duration covering a period of slow fireball growth. The data from two cameras is presented in Tables 3.1 and 3.2 and Figures 3.1 through 3.19.

3.1.2 Calorimetric Data. Of the 44 calorimeters used, 42 gave valid results. No data was lost, inasmuch as adequate duplication of measurements were made. Failure of the time-line generator on one recorder caused no difficulties, because the alternate means of determining times proved adequate. The data is presented in Tables 3.3 and 3.4.

TABLE 3.4 LACROSSE CALORIMETER DATA, SITE WILMA

Time	Scaled Time	FV 160 Q	FV 160 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	FV 45 Q	FV 45 Q
sec	t/t_{2max}									
0.00	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.11	0.5	0.051	0.049	0.048	0.063	0.056	0.061	0.055	0.053	0.048
0.20	0.9	0.172	0.170	0.169	0.188	0.179	0.194	0.187	0.177	0.179
0.24	1.1	0.257	0.255	0.242	0.262	0.257	0.279	0.274	0.249	0.251
0.31	1.4	0.394	0.401	0.387	0.413	0.402	0.436	0.428	0.373	0.371
0.40	1.8	0.565	0.559	0.556	0.587	0.566	0.606	0.604	0.497	0.514
0.57	2.6	0.772	0.767	0.776	0.800	0.790	0.827	0.826	0.676	0.696
0.88	4.0	0.999	0.958	1.002	1.032	1.013	1.056	0.057	0.877	0.883
1.32	6.0	1.145	1.096	1.142	1.173	1.164	1.201	1.201	1.016	1.006
2.20	10.0	1.290	1.223	1.288	1.314	1.304	1.342	1.344	1.141	1.128
3.52	16.0	1.332	1.268	1.344	1.368	1.360	1.392	1.388	1.185	1.167
6.60	30.0	1.334	1.273	1.361	1.381	1.366	1.401	1.403	1.197	1.171
∞	∞	1.337	1.282	1.383	1.406	1.389	1.426	1.428	1.200	1.180

Time	Scaled Time	FV 22 Q	FV 22 Q	FV 11 Q	FV 11 Q	SP 90 0-52	SP 90 3-69	SP 90 2-58	SP 90 7-56	SP 90 7-56
sec	t/t_{2max}									
0.00	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.11	0.5	0.024	0.022	0.020	0.024	0.066	0.056	0.048	0.023	0.022
0.20	0.9	0.121	0.127	0.104	0.104	0.198	0.161	0.133	0.045	0.056
0.24	1.1	0.181	0.192	0.156	0.163	0.275	0.221	0.181	0.056	0.069
0.31	1.4	0.290	0.312	0.250	0.257	0.429	0.344	0.278	0.090	0.103
0.40	1.8	0.423	0.433	0.354	0.374	0.607	0.488	0.392	0.135	0.138
0.57	2.6	0.594	0.608	0.501	0.528	0.827	0.670	0.551	0.181	0.196
0.88	4.0	0.794	0.793	0.652	0.664	1.056	0.867	0.730	0.240	0.267
1.32	6.0	0.929	0.927	0.746	0.759	1.201	0.998	0.852	0.300	0.328
2.20	10.0	1.049	1.051	0.835	0.847	1.318	1.109	0.956	0.378	0.395
3.52	16.0	1.082	1.086	0.867	0.876	1.366	1.151	0.996	0.414	0.429
6.60	30.0	1.088	1.089	0.870	0.878	1.371	1.155	1.000	0.417	0.431
∞	∞	1.089	1.091	0.876	0.882	1.393	1.166	1.009	0.423	0.435

3.1.3 Radiometric Data. The irradiance versus time for Sites Yvonne and Wilma is plotted in Figures 3.20 and 3.21, respectively. The continuous curves are radiometer data, which are useful primarily for obtaining a qualitative picture of the pulse shape. The average irradiance, as determined from the calorimeters at each station, is shown as a series of horizontal lines. All data shown have been corrected for the transmission of the quartz filters used on the instruments.

3.1.4 Meteorological and Device Data. Shot Lacrosse was detonated on a pier extending northward from Site Yvonne. The cab was about 17 feet above the surface of water about 2 feet deep. Extensive hardware and piping extended from the cab toward Site Yvonne. These pipes may be seen in Figures 3.16 and 3.17 as they are carried away by the shock wave. The recommended total yield is 39.5 kt (Reference 4). The air temperature was 81 F, dew point 77 F, and the relative humidity 84 percent. The visibility was greater than 10 miles and the cloud cover was negligible.

TABLE 3.5 CHEROKEE PHOTOGRAPHIC DATA, F-84-350

Roll ID Number: Cherokee F-84-350 NRDL 5.5-4
Slant Range: 137,520 feet at time zero
Camera: GSAP AN-9

Speed: 32 frames/sec
Focal Length: 17 mm
Film: Kodachrome

Frame	Time	Radius	Figure Number	Frame	Time	Radius	Figure Number
	sec	meter			sec	meter	
1	0.031	330		35	1.094	1,041	
2	0.063	486		40	1.250	1,128	3.23
3	0.097	590		50	1.560	1,094	
11	0.344	807		60	1.875	1,197	3.24
12	0.375	816		80	2.50	1,302	3.24
13	0.406	790		100	3.125	1,250	3.25
14	0.438	816		150	4.670	1,423	3.25
15	0.469	885	3.23	200	6.250	1,440	3.26
30	0.938	963					

TABLE 3.6 CHEROKEE FIREBALL DIAMETERS*

Time	Radius
sec	meter
1.10	965
1.40	1,035

* Courtesy of Dr. Lewis Fussell, Jr., of Edgerton, Germeshausen and Grier, Inc.

3.2 SHOT CHEROKEE

Although all instrumentation functioned properly, the data obtained is of limited usefulness, due to an unexpectedly large error in the position of the burst.

3.2.1 Photographic Data. No pictorial information was obtained concerning fireball diameters, because the fireball was outside of the field of view at all stations. The photographic films show a layer of cumulus clouds of variable density obscuring all stations. Sites George and How appear to have been obscured more than Site Dog.

Cherokee fireball diameters versus time were obtained from films and data supplied by other projects and are listed in Tables 3.5 and 3.6 and plotted in Figure 3.22. The data of Table 3.5 was measured from Film F-84 350 NRDL 5.5-4 supplied through the courtesy of Wright Air Development Center (WADC) and Project 5.5, prints of which are shown in Figures 3.23 through 3.32. The data of Table 3.6 were supplied by letter from Dr. Lewis Fussell, Jr., of Edgerton, Germeshausen and Grier, Inc. (EG&G).

3.2.2 Calorimetric Data. Successful thermal measurements were made from stations on

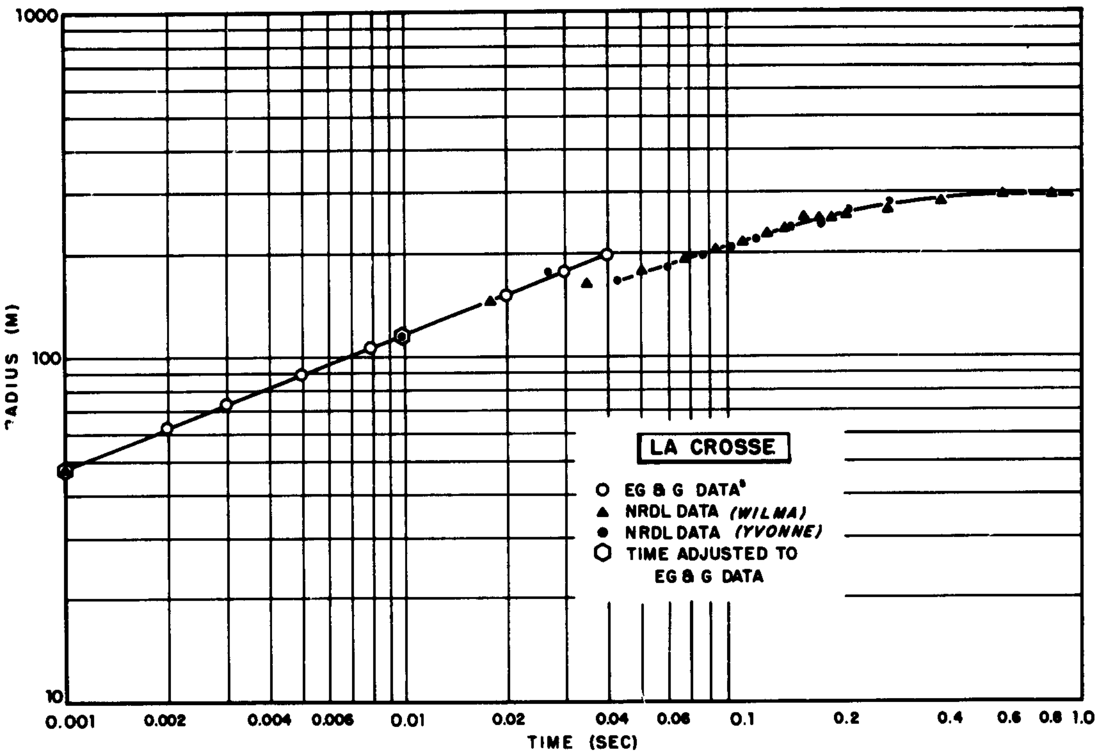


Figure 3.1 Shot Lacrosse fireball radius versus time.

Sites Dog, George, and How. The usefulness of data from one of the two recorders on Site Dog was decreased by a timer failure. Data from this recorder is satisfactory, however, for the determination of total energy and can even be used to determine color temperature, but the data cannot be directly compared with other shots on the basis of scaled time intervals.

The data from all stations show the effects of cloud obscuration. The magnitude of this effect is not known, inasmuch as the fireball was out of the field of view of the cameras employed to measure this parameter. Thus, the accuracy of the thermal data is lowered not by the error in burst position itself, but by the lack of knowledge of the cloud obscuration. This situation will be discussed further in the next chapter.

In all cases, the fireball was within the field of view of the standard thermal instruments. The alignment errors, (θ), were 32.5, 21.5, and 11.2 degrees for Sites Dog, George, and How, respectively. The combination of alignment error due to the miss distance and unknown cloud obscuration made the field-of-view measurements impossible to interpret. For this reason

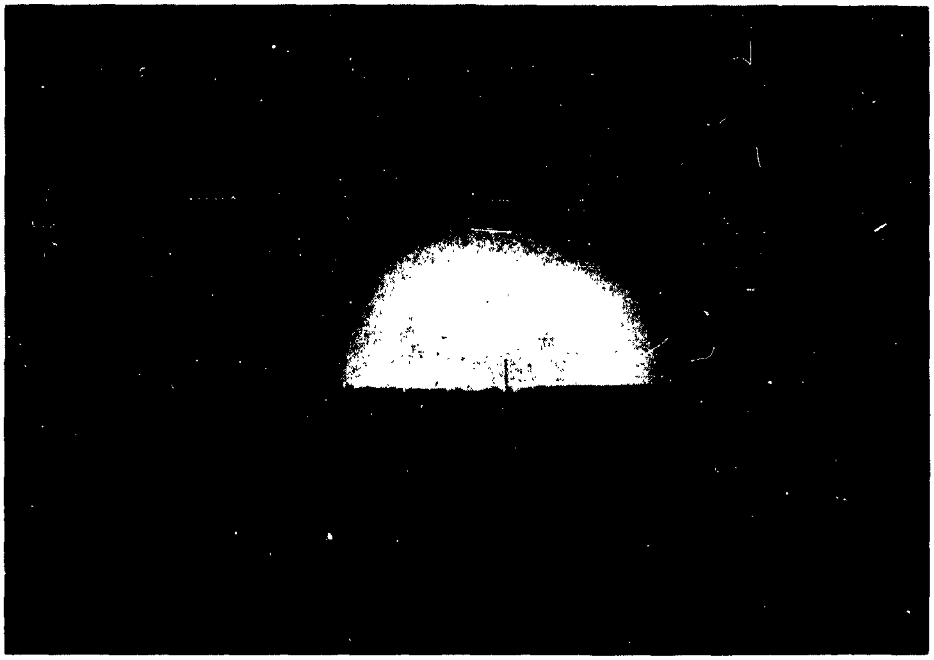


Figure 3.2 Shot Lacrosse from Site Yvonne at 0.010 sec.

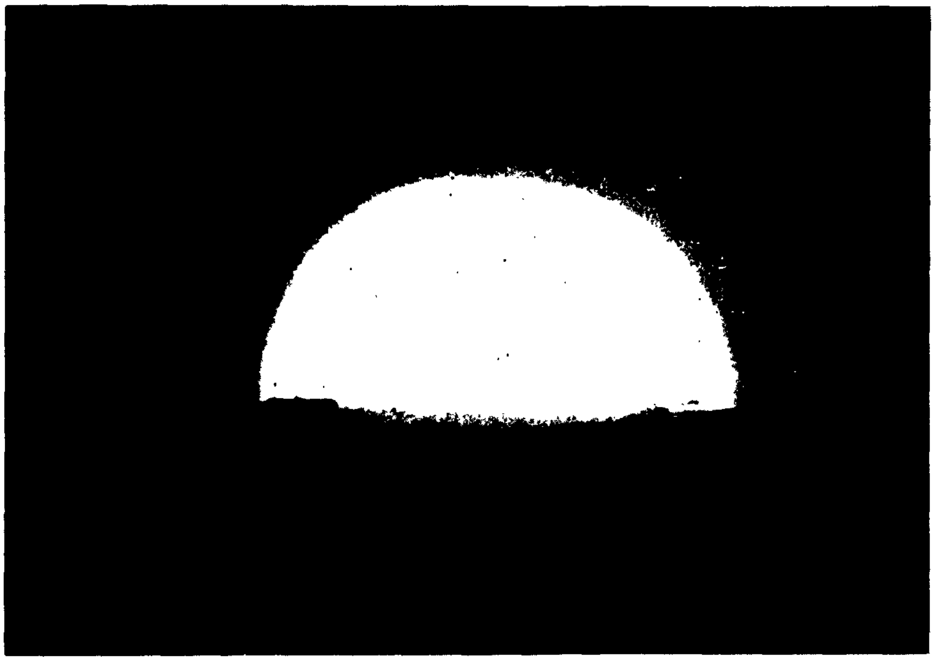


Figure 3.3 Shot Lacrosse from Site Yvonne at 0.027 sec.

Figure 3.4 Shot Lacrosse from Site Yvonne at 0.043 sec.

Figure 3.5 Shot Lacrosse from Site Yvonne at 0.060 sec.

Figure 3.6 Shot Lacrosse from Site Yvonne at 0.077 sec.

Figure 3.7 Shot Lacrosse from Site Yvonne at 0.094 sec.

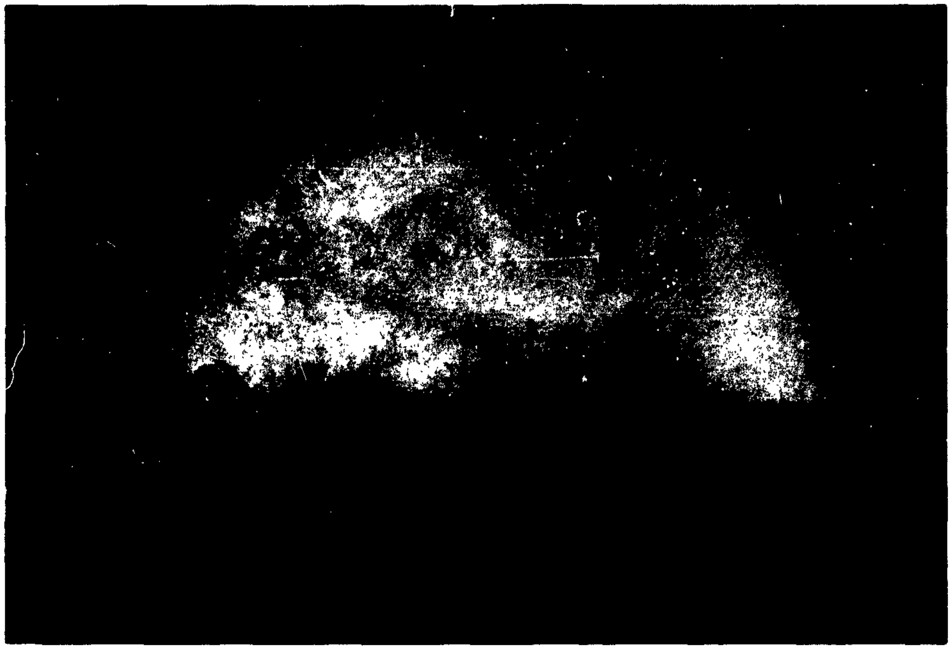


Figure 3.8 Shot Lacrosse from Site Yvonne at 0.110 sec.

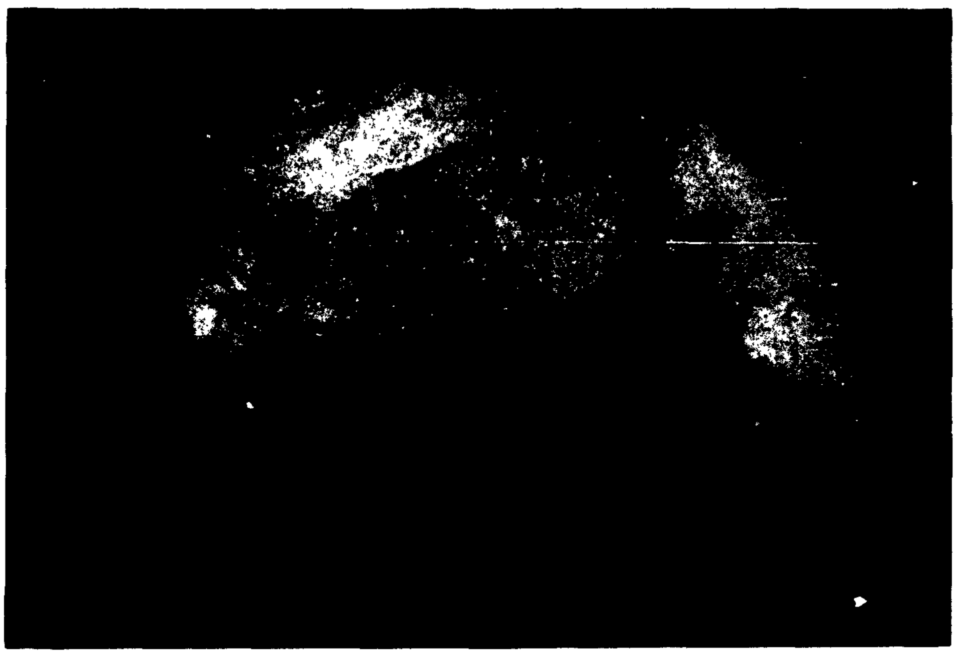


Figure 3.9 Shot Lacrosse from Site Yvonne at 0.172 sec.

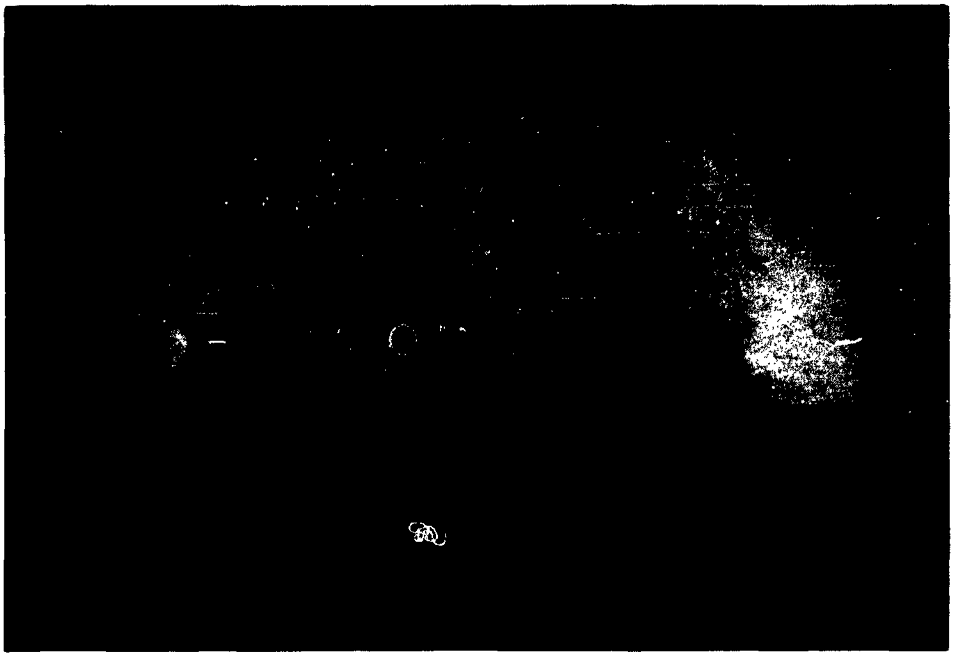


Figure 3.10 Shot Lacrosse from Site Yvonne at 0.205 sec.

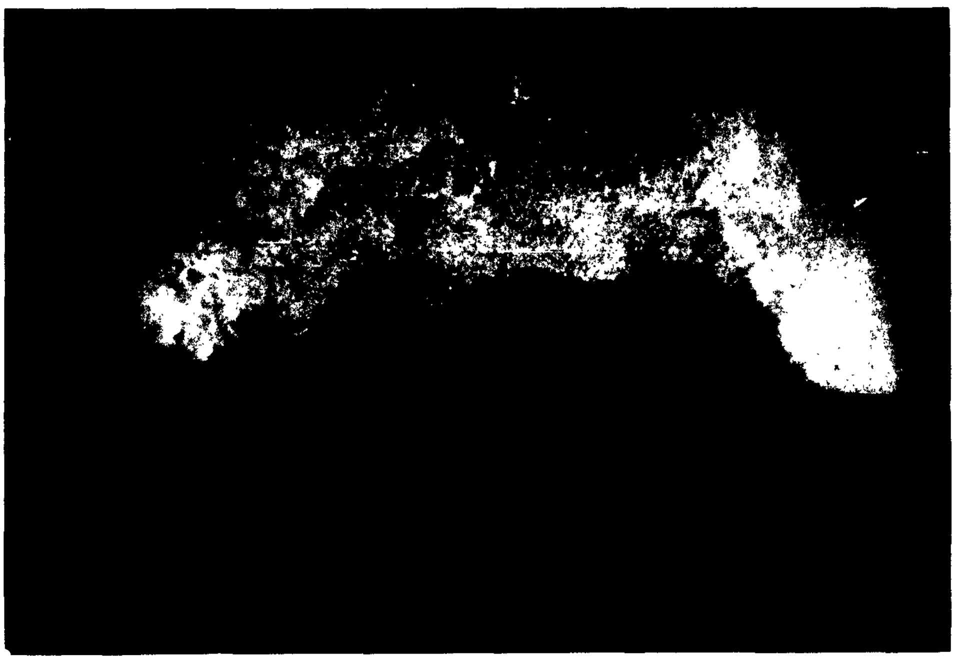


Figure 3.11 Shot Lacrosse from Site Yvonne at 0.27 sec.

they are not included in this report, but are on file for possible future reference. Calorimeter data for the various stations are reported in Tables 3.7 through 3.10.

3.2.3 Radiometric Data. Radiometric data are shown in Figures 3.28 through 3.30 for the stations on Sites Dog, George, and How, respectively. In all cases the deflections were low, making the time to second maximum difficult to locate exactly. In all cases, however, the time to second maximum was between 1.4 and 1.6 seconds. The radiometer deflection was extremely low at Site Dog, so the data should not be used quantitatively. The irradiances, as determined by the calorimeters, are also shown in Figures 3.28 through 3.30. Both radiometer and calorimeter data have been corrected for instrument filter transmission and for alignment error.

TABLE 3.7 CHEROKEE CALORIMETER DATA, SITE DOG

The timer on this recorder failed on this shot so that the times listed in Column 1 are not accurate. Energy values listed in this table cannot be correlated directly with other measurements, except for the final values.

Time	Scaled Time	FV 160 Q	TE 90 Q	TE 90 Q	TE 90 Q	SP 90 3-69	SP 90 2-58	SP 90 RG8	SP 90 7-56
sec	t/t_{2max}								
00.00	0.0	00.000	00.000	00.000	00.000	00.000	00.000	00.000	00.000
00.78	0.5	02.581	02.301	02.676	02.572	02.354	02.227	02.114	00.907
01.40	0.9	14.000	12.227	13.277	13.265	11.646	09.460	08.648	03.048
01.71	1.1	21.398	19.209	20.326	20.034	17.399	13.563	12.303	04.119
02.17	1.4	32.291	29.323	30.317	30.060	25.291	19.160	16.910	05.491
02.79	1.8	43.693	39.959	40.714	40.531	33.497	25.036	21.719	06.989
04.03	2.6	58.031	53.048	53.534	53.213	43.674	32.608	28.151	08.997
06.20	4.0	69.682	62.707	63.266	62.984	51.067	38.575	33.451	10.846
09.30	6.0	76.803	68.027	68.582	68.116	55.347	42.021	36.727	12.370
∞	∞	79.983	68.537	68.934	68.346	55.829	42.351	37.628	13.414

TABLE 3.8 CHEROKEE CALORIMETER DATA, SITE DOG

Time	Scaled Time	FV 160 Q	TE 90 Q	TE 90 Q	TE 90 Q	SP 90 0-52	SP 90 2-58
sec	t/t_{2max}						
00.00	0.0	00.000	00.000	00.000	00.000	00.000	00.000
00.78	0.5	03.244	03.029	03.084	03.082	02.898	02.492
01.40	0.9	15.676	14.981	15.458	14.437	14.479	10.450
01.71	1.1	23.657	22.409	23.121	21.756	21.622	14.853
02.17	1.4	34.245	32.517	33.505	31.207	31.320	20.551
02.79	1.8	44.922	42.765	43.738	40.970	40.984	26.383
04.03	2.6	58.210	55.751	56.604	53.025	53.022	33.992
06.20	4.0	68.308	62.766	65.968	61.836	61.905	39.895
09.30	6.0	73.986	68.000	70.823	66.464	66.450	42.963
∞	∞	73.986	71.362	70.935	66.327	66.590	43.059

3.2.4 Meteorological and Device Data. Cherokee was a 3.8-Mt air burst detonated at an

TABLE 3.9 CHEROKEE CALORIMETER DATA, SITE GEORGE

Time	Scaled Time	FV 160 Q	FV 160 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q
sec	t/t_{2max}						
00.00	0.0	00.000	00.000	00.000	00.000	00.000	00.000
00.78	0.5	00.889	00.970	00.916	00.947	00.979	00.895
01.40	0.9	04.527	04.800	04.748	04.634	04.691	04.525
01.71	1.1	06.601	07.112	06.998	06.844	06.981	06.666
02.17	1.4	09.391	10.150	09.931	09.743	09.945	09.494
02.79	1.8	11.980	12.870	12.605	12.388	12.685	12.130
04.03	2.6	14.961	15.996	15.681	15.427	15.796	15.116
06.20	4.0	17.014	18.150	17.789	17.515	17.970	17.296
09.30	6.0	18.190	19.491	19.002	18.767	19.255	18.470
∞	∞	18.243	19.627	19.096	19.130	19.472	18.632

Time	Scaled Time	TE 90 Q	SP 90 0-52	SP 90 3-69	SP 90 2-58	SP 90 2-58	SP 90 7-56
sec	t/t_{2max}						
00.00	0.0	00.000	00.000	00.000	00.000	00.000	00.000
00.78	0.5	00.871	00.866	00.887	00.861	00.797	00.324
01.40	0.9	04.701	04.523	04.118	03.384	03.372	01.051
01.71	1.1	06.886	06.636	05.910	04.736	04.634	01.413
02.17	1.4	09.814	09.515	08.258	06.430	06.369	01.872
02.79	1.8	12.551	12.171	10.437	08.083	08.009	02.350
04.03	2.6	15.572	15.270	13.027	10.097	10.064	02.935
06.20	4.0	17.673	17.451	14.886	11.474	11.548	03.358
09.30	6.0	19.081	18.701	15.892	12.349	12.342	03.690
∞	∞	19.290	18.922	16.079	12.475	12.525	03.639

TABLE 3.10 CHEROKEE CALORIMETER DATA, SITE HOW

Time	Scaled Time	FV 160 Q	FV 160 Q*	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q*	TE 90 Q*
sec	t/t_{2max}							
00.00	0.0	00.000	00.000	00.000	00.000	00.000	00.000	00.000
00.78	0.5	00.114	00.346	00.122	00.113	00.104	00.338	00.358
01.40	0.9	00.479	00.764	00.510	00.510	00.474	00.786	00.828
01.71	1.1	00.720	00.948	00.756	00.716	00.696	00.952	01.014
02.17	1.4	00.978	01.129	01.031	01.007	00.982	01.158	01.197
02.79	1.8	01.190	01.287	01.265	01.244	01.225	01.314	01.358
04.03	2.6	01.426	01.447	01.487	01.465	01.454	01.501	01.526
06.20	4.0	01.562	01.541	01.657	01.606	01.593	01.608	01.664
09.30	6.0	01.657	01.602	01.744	01.689	01.674	01.693	01.752
15.50	10.0	01.688	01.649	01.822	01.764	01.757	01.771	01.814
24.80	16.0	01.751	01.680	01.900	01.840	01.851	01.874	01.938
∞	∞	01.794	01.748	01.994	01.919	01.950	01.937	02.073

Time	Scaled Time	TE 90 Q*	SP 90 0-52	SP 90 3-69*	SP 90 2-58*	SP 90 2-58	SP 90 7-56	SP 90 7-56*
sec	t/t_{2max}							
00.00	0.0	00.000	00.000	00.000	00.000	00.000	00.000	00.000
00.78	0.5	00.349	00.117	00.335	00.265	00.092	00.035	00.086
01.40	0.9	00.796	00.494	00.697	00.525	00.349	00.117	00.153
01.71	1.1	00.966	00.708	00.866	00.641	00.479	00.142	00.187
02.17	1.4	01.157	00.999	01.014	00.752	00.648	00.202	00.223
02.79	1.8	01.326	01.233	01.142	00.860	00.791	00.254	00.261
04.03	2.6	01.493	01.462	01.287	00.962	00.948	00.313	00.308
06.20	4.0	01.622	01.584	01.377	01.037	01.020	00.363	00.336
09.30	6.0	01.713	01.640	01.440	01.091	01.079	00.391	00.376
15.50	10.0	01.797	01.685	01.487	01.134	01.133	00.430	00.420
24.80	16.0	01.905	01.741	01.566	01.233	01.199	00.492	00.500
∞	∞	02.035	01.787	01.673	01.344	01.260	00.585	00.631

* The timer on this recorder did not work accurately. Data from this recorder cannot be directly correlated timewise with other data.

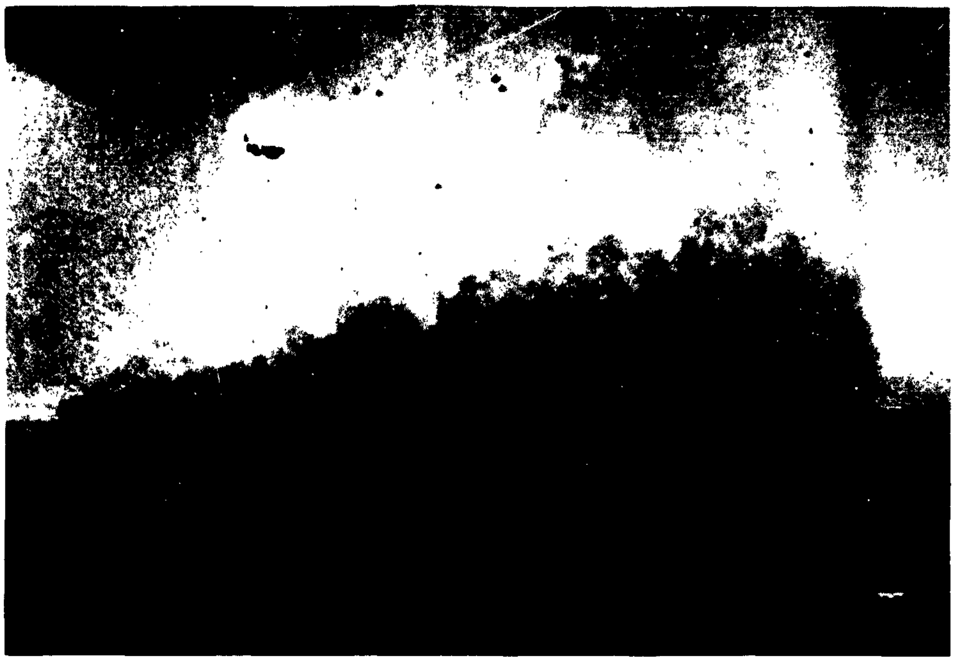


Figure 3.12 Shot Lacrosse from Site Yvonne at 0.39 sec.

Figure 3.13 Shot Lacrosse from Site Yvonne at 0.59 sec.

Figure 3.14 Shot Lacrosse from Site Yvonne at 0.83 sec.

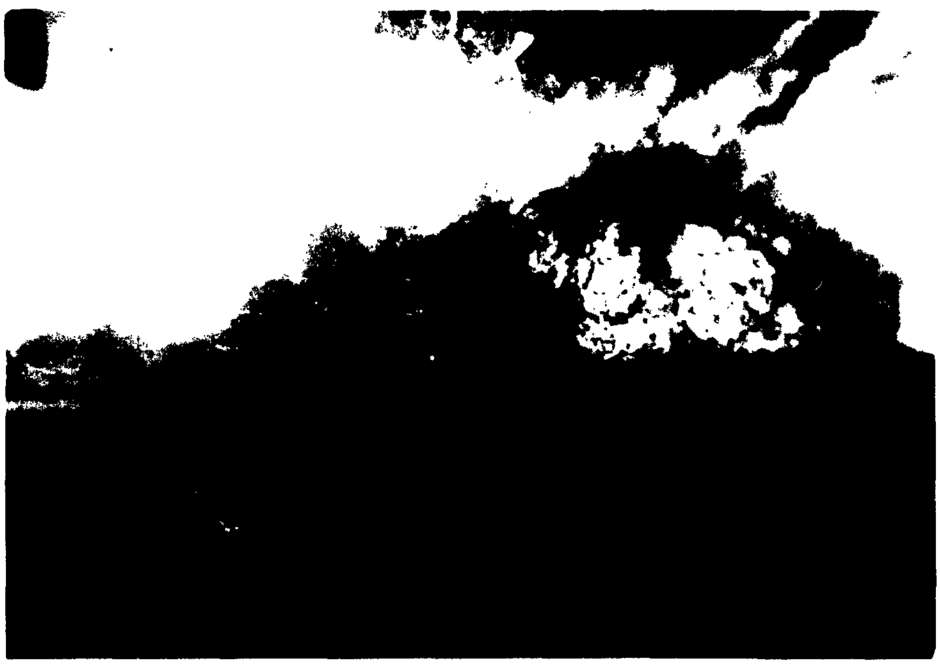


Figure 3.15 Shot Lacrosse from Site Yvonne at 1.46 sec.

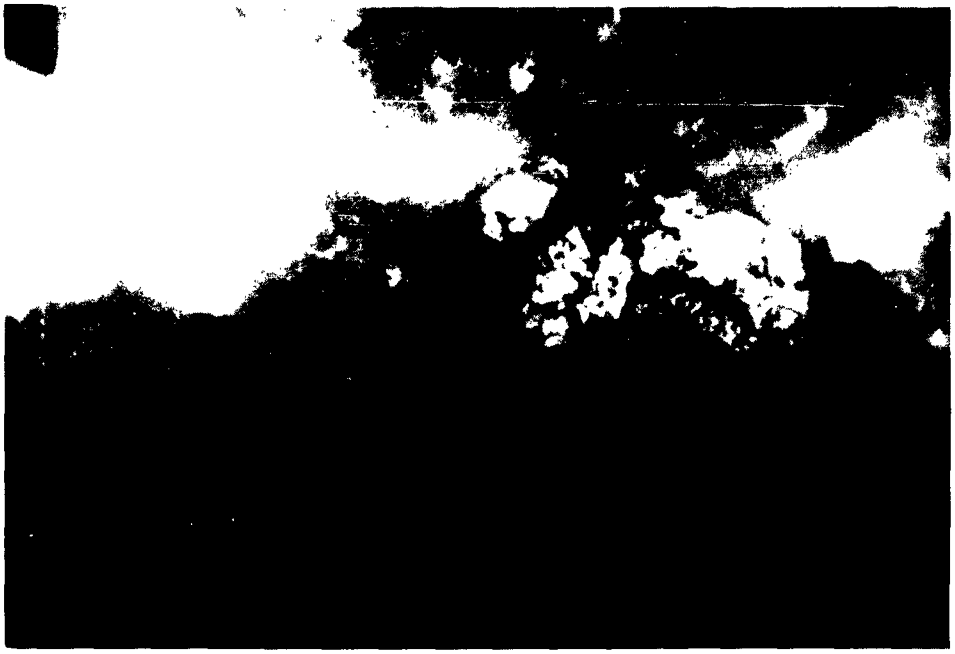


Figure 3.16 Shot Lacrosse from Site Yvonne at 2.38 sec.

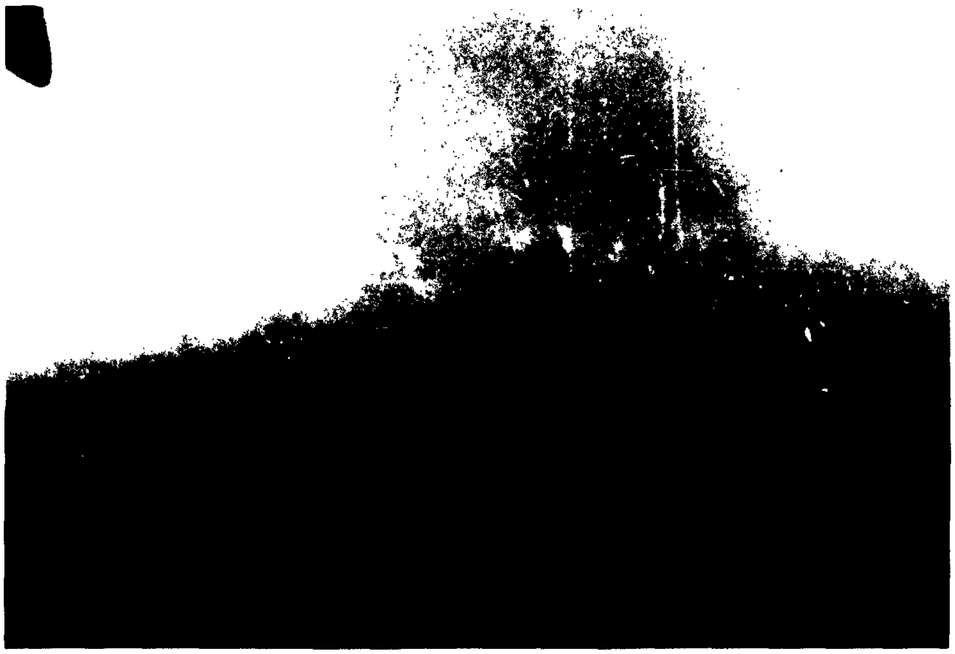


Figure 3.17 Shot Lacrosse from Site Yvonne at 2.99 sec.

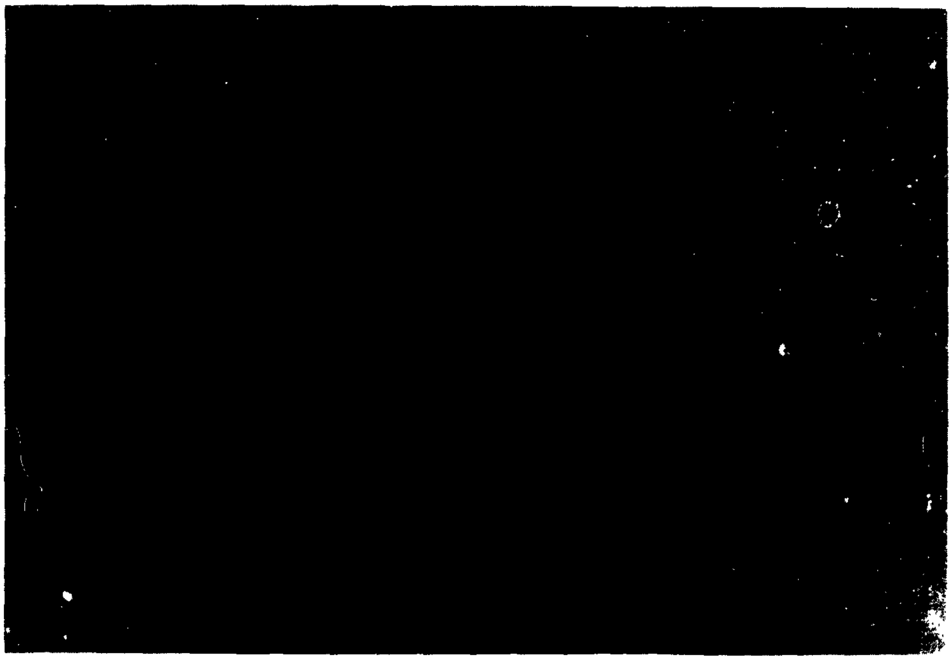


Figure 3.18 Shot Lacrosse from Site Yvonne at 4.42 sec.

Figure 3.19 Shot Lacrosse from Site Yvonne at 5.49 sec.

altitude of approximately 4,300 feet. The burst position was approximately 19,000 feet northeast of the planned air zero. The air temperature was 81 F, dew point 73 F, and the relatively humidity 76 percent. The visibility was greater than 10 miles. The cloud cover was 0.2 cumulus between 1,800 and 2,500 feet, and 0.2 cirrus at 38,000 feet.

3.3 SHOT ZUNI

Data of adequate quality and quantity were obtained from stations on Sites Nan and William. The data from Site Oboe was negated by heavy smoke obscuration and the failure of a field calibrator. Since data for Site Oboe can be extrapolated from the Nan and William data with less uncertainty than if an attempt is made to use the Oboe data, it was deemed unncessary to publist these data.

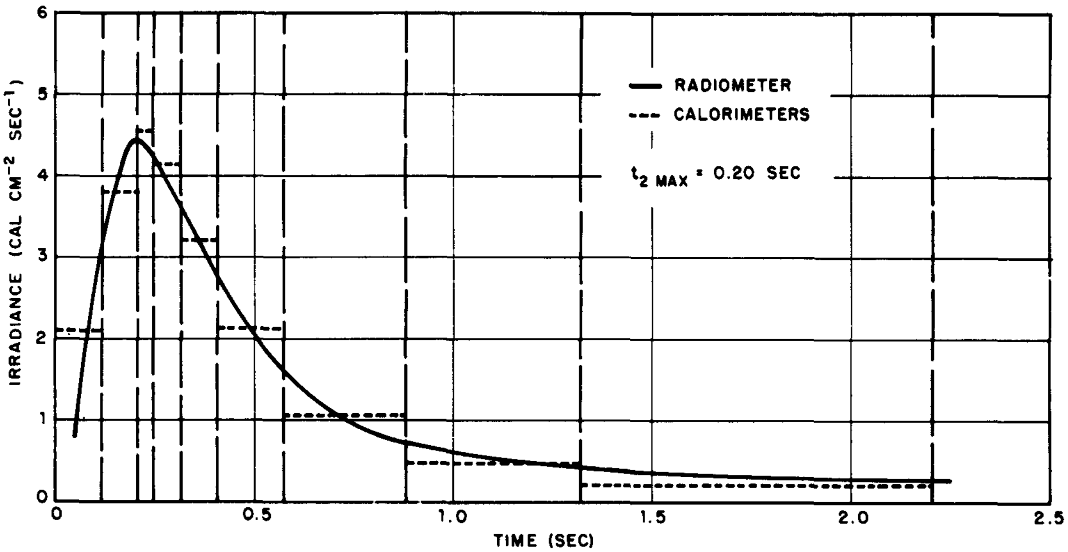


Figure 3.20 Shot Lacrosse irradiance versus time, Site Yvonne.

3.3.1 Photographic Data. Successful photographic measurements were completed at all stations. Data from Sites William and Nan are included in Tables 3.11 and 3.12 and Figures 3.31 through 3.43 in order to interpret the calorimetric results. The radius of the fireball is plotted in Figure 3.44. The apparent lessening in size after 2 seconds may be seen in Figures 3.36, 3.37, 3.38, 3.42, and 3.43.

3.3.2 Calorimetric Data. Successful calorimetric measurements were completed from the Site William station and from two stations on Site Nan. Data from one of the two recorders at Site William is not reported because of a timer failure. Data from Site Oboe was negated by a faulty calibrator that was not discovered until after the shot. Close proximity to ground zero made postshot calibration unfeasible. It is doubted that the data could be interpreted, had it been accurate, because of extensive smoke obscuration between the station and the fireball. The data from the William and Nan stations are given in Tables 3.13 through 3.15.

3.3.3 Radiometric Data. Irradiance versus time is plotted for the William station and the two Nan stations in Figures 3.45 through 3.47. Times to second maximum are not well defined, due to low deflection on the radiometers.

3.3.4 Meteorological and Device Data. Zuni was a 3.5-Mt surface burst detonated on Site Tare. The fireball spread over both land and water surfaces. The air temperature was 81 F, dew point 76 F, and the relative humidity 80 percent. Although the visibility is reported by various observers as 5.4 miles and 8 miles, the photographic data from the Nan station at 13 miles shows good detail in the area of ground zero.

TABLE 3.11 ZUNI PHOTOGRAPHIC DATA, SITE WILLIAM

Roll ID Number: 150303
Slant Range: 32,073 feet (Station 810.02, William)
Camera: GSAP Mod-B with 30 deg shutter
Speed: 98 frames/sec (at time zero), 79 at frame 400
Focal Length: 35.23 mm
Exposure: f:4.5 with ND-3 filter
Film: 16 mm Microfile SO-1112 (ASA-1)

Frame	Time	Radius	Figure Number	Frame	Time	Radius	Figure Number
	sec	meter			sec	meter	
1	0.002	155	3.31	30	0.280	—	3.34
2	0.0105	287	3.31	42	0.440	—	3.34
3	0.0215	369	3.31	115	1.20	1,075	3.35
4	0.0325	427	3.31	160	1.75	1,162	3.35
5	0.0435	474	3.32	202	2.27	1,193	3.36
6	0.0595	516	3.32	258	3.05	1,188	3.36
7	0.0650	551	3.32	355	4.35	1,140	3.37
8	0.0765	586	3.32	529	6.50	1,040	3.37
9	0.0875	618	3.33	846	9.30	848	3.38
10	0.0990	648	3.33	1,000	11.0	—	3.38
11	0.1095	676	3.33				
12	0.1210	699	3.33				

TABLE 3.12 ZUNI PHOTOGRAPHIC DATA, SITE NAN

Roll ID Number: 150309
Slant Range: 68,580 feet (Station 813.01 on Nan Tower)
Camera: GSAP Mod-B with 30 deg shutter
Speed: 91 frames/sec (at time zero), 74 at frame 400
Focal Length: 35.31 mm
Exposure: f:16 with ND-2 filter
Film: 16 mm Microfile SO-1112 (ASA-1)

Frame	Time	Radius	Figure Number	Frame	Time	Radius	Figure Number
	sec	meter			sec	meter	
1	0.002	135	3.39	81	0.975	970	—
2	0.0135	308	3.39	115	1.135	1,105	3.40
3	0.0260	394	3.39	160	1.95	1,178	3.41
4	0.038	457	3.39	202	2.60	1,191	3.41
5	0.052	506	3.39	258	3.40	1,177	3.42
6	0.0645	550	3.39	355	4.80	1,123	3.42
7	0.0775	591	3.39	529	7.0	1,009	3.43
42	0.480	—	3.40	846	9.60	845	3.43

TABLE 3.13 ZUNI CALORIMETER DATA, SITE WILLIAM

Time	Scaled Time	FV 160 Q	TE 90 Q	TE 90 Q	FV 45 Q	FV 22 Q	FV 11 Q	SP 90 0-52	SP 90 2-58	SP 90 7-56
sec	t/t_{2max}									
0.00	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.98	0.5	0.877	0.885	0.885	0.735	0.624	0.420	0.825	0.665	0.230
1.76	0.9	4.287	4.397	4.395	3.659	3.108	2.163	4.340	3.090	0.959
2.15	1.1	6.583	6.767	6.759	5.682	4.750	3.340	6.730	4.553	1.372
2.73	1.4	9.789	9.909	9.917	8.362	6.941	4.879	9.880	6.522	1.922
3.51	1.8	12.920	12.979	12.962	10.896	9.103	6.146	12.972	8.501	2.520
5.07	2.6	16.403	16.466	16.482	13.802	11.503	7.532	16.464	11.033	3.326
7.80	4.0	19.724	19.836	19.643	16.543	13.727	8.749	19.790	13.567	4.288
11.70	6.0	21.255	21.658	21.440	17.859	14.615	9.337	21.495	14.953	4.914
19.50	10.0	21.354	21.976	21.743	18.006	14.684	9.364	21.735	15.168	5.073
31.20	16.0	21.475	22.304	22.095	18.123	14.766	9.393	21.984	15.365	5.278
58.50	30.0	22.144	23.536	23.381	18.466	15.007	9.463	22.648	15.724	5.836
∞	∞	22.071	23.866	23.764	18.544	15.076	9.464	22.798	15.787	5.927

TABLE 3.14 ZUNI CALORIMETER DATA, SITE NAN, 42-FOOT TOWER

Time	Scaled Time	FV 160 Q	FV 160 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	FV 45 Q	FV 45 Q
sec	t/t_2max									
0.00	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.98	0.5	0.043	0.092	0.092	0.096	0.086	0.088	0.087	0.060	0.063
1.76	0.9	0.345	0.342	0.347	0.348	0.349	0.346	0.350	0.266	0.268
2.15	1.1	0.505	0.540	0.511	0.518	0.513	0.508	0.515	0.388	0.397
2.73	1.4	0.771	0.745	0.726	0.740	0.733	0.724	0.735	0.564	0.569
3.51	1.8	0.964	0.985	0.964	0.974	0.975	0.963	0.978	0.760	0.761
5.07	2.6	1.280	1.248	1.216	1.223	1.230	1.219	1.225	0.962	0.964
7.80	4.0	1.514	1.484	1.467	1.468	1.479	1.462	1.468	1.152	1.152
11.70	6.0	1.705	1.642	1.615	1.615	1.621	1.616	1.632	1.273	1.273
19.50	10.0	1.855	1.773	1.748	1.741	1.735	1.734	1.746	1.371	1.375
31.20	16.0	2.097	1.964	1.965	1.960	1.950	1.935	1.959	1.523	1.529
58.50	30.0	2.281	2.143	2.032	2.017	2.006	2.060	2.008	1.577	1.582
∞	∞	2.291	2.150	2.029	2.042	2.033	2.014	2.046	1.576	1.569

Time	Scaled Time	FV 22 Q	FV 22 Q	FV 11 Q	SP 90 0-52	SP 90 3-69	SP 90 2-58	SP 90 7-56	SP 90 7-56
sec	t/t_2max								
0.00	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.98	0.5	0.049	0.048	0.037	0.087	0.071	0.068	0.030	0.027
1.76	0.9	0.208	0.203	0.175	0.339	0.287	0.244	0.091	0.084
2.15	1.1	0.305	0.299	0.264	0.506	0.432	0.350	0.132	0.126
2.73	1.4	0.445	0.436	0.369	0.731	0.617	0.496	0.174	0.169
3.51	1.8	0.591	0.577	0.502	0.967	0.824	0.661	0.228	0.226
5.07	2.6	0.739	0.728	0.627	1.221	1.051	0.844	0.292	0.294
7.80	4.0	0.884	0.871	0.746	1.479	1.288	1.054	0.371	0.381
11.70	6.0	0.984	0.965	0.820	1.635	1.433	1.182	0.439	0.448
19.50	10.0	1.052	1.034	0.891	1.754	1.544	1.289	0.518	0.524
31.20	16.0	1.117	1.096	0.950	1.964	1.717	1.462	0.706	0.712
58.50	30.0	1.136	1.119	0.963	2.017	1.750	1.499	0.746	0.756
∞	∞	1.145	1.124	0.965	2.023	1.752	1.510	0.750	0.760

TABLE 3.15 ZUNI CALORIMETER DATA, SITE NAN, 200-FOOT TOWER

Time	Scaled Time	FV 160 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	TE 90 Q	FV 45 Q	FV 45 Q
sec	t/t_{2max}									
0.00	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.98	0.5	0.034	0.086	0.085	0.083	0.081	0.080	0.083	0.043	0.045
1.76	0.9	0.285	0.336	0.340	0.330	0.326	0.330	0.331	0.250	0.249
2.15	1.1	0.448	0.499	0.500	0.485	0.492	0.491	0.487	0.371	0.376
2.73	1.4	0.659	0.712	0.727	0.705	0.710	0.704	0.705	0.540	0.541
3.51	1.8	0.873	0.947	0.965	0.949	0.952	0.940	0.939	0.730	0.736
5.07	2.6	1.125	1.199	1.221	1.200	1.211	1.195	1.192	0.938	0.948
7.80	4.0	1.367	1.444	1.466	1.454	1.467	1.445	1.440	1.112	1.122
11.70	6.0	1.533	1.609	1.640	1.633	1.635	1.615	1.612	1.229	1.238
19.50	10.0	1.717	1.790	1.820	1.814	1.815	1.800	1.797	1.356	1.363
31.20	16.0	1.973	2.057	2.090	2.082	2.090	2.072	2.065	1.527	1.535
58.50	30.0	2.176	2.190	2.234	2.227	2.199	2.217	2.198	1.642	1.629
∞	∞	2.185	2.192	2.235	2.228	2.201	2.222	2.203	1.639	1.640

Time	Scaled Time	FV 22 Q	FV 22 Q	FV 11 Q	FV 11 Q	SP 90 0-52	SP 90 3-69	SP 90 2-58	SP 90 7-56	SP 90 7-56
sec	t/t_{2max}									
0.00	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.98	0.5	0.050	0.041	0.058	0.055	0.083	0.072	0.067	0.025	0.022
1.76	0.9	0.213	0.199	0.187	0.181	0.331	0.278	0.245	0.084	0.077
2.15	1.1	0.316	0.305	0.269	0.263	0.487	0.421	0.348	0.120	0.110
2.73	1.4	0.454	0.447	0.379	0.371	0.709	0.602	0.499	0.158	0.154
3.51	1.8	0.600	0.595	0.495	0.485	0.930	0.793	0.657	0.211	0.200
5.07	2.6	0.751	0.749	0.631	0.620	1.186	1.020	0.845	0.275	0.276
7.80	4.0	0.899	0.896	0.764	0.748	1.428	1.238	1.038	0.358	0.359
11.70	6.0	0.999	1.001	0.851	0.833	1.596	1.394	1.178	0.429	0.427
19.50	10.0	1.094	1.099	0.923	0.900	1.776	1.560	1.336	0.538	0.530
31.20	16.0	1.178	1.188	0.949	0.957	2.037	1.775	1.536	0.780	0.760
58.50	30.0	1.267	1.276	1.024	1.020	2.173	1.859	1.623	0.881	0.866
∞	∞	1.275	1.280	1.026	1.031	2.179	1.861	1.624	0.885	0.869

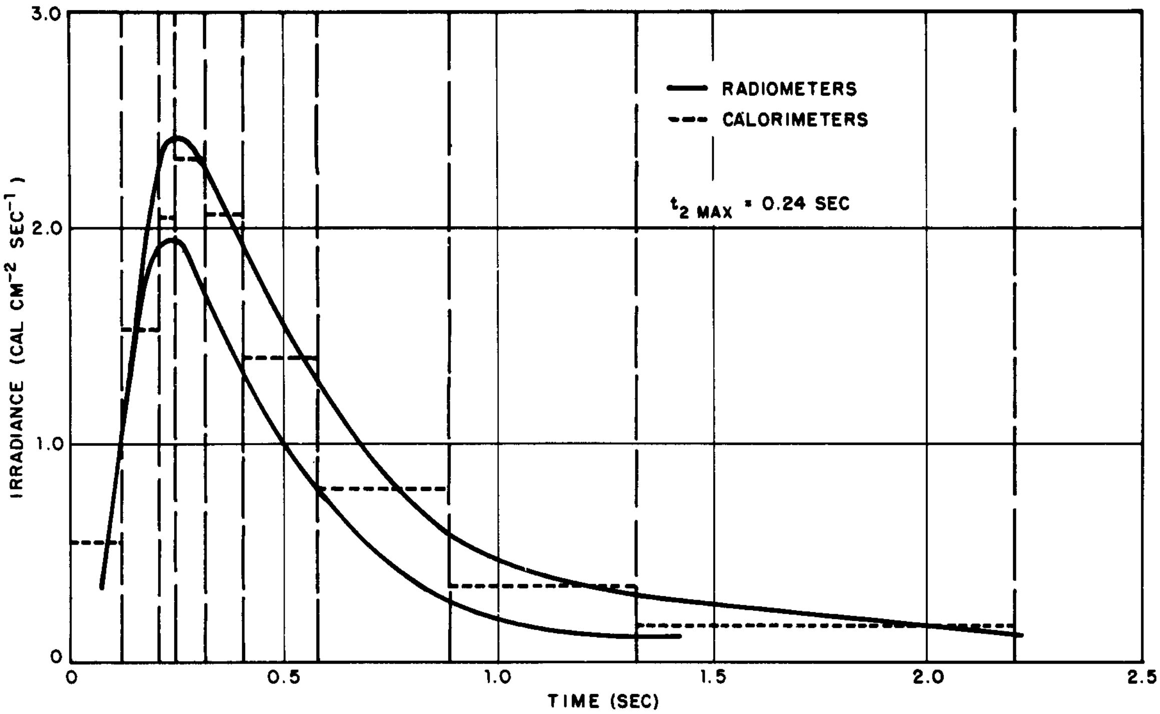


Figure 3.21 Shot Lacrosse irradiance versus time, Site Wilma.

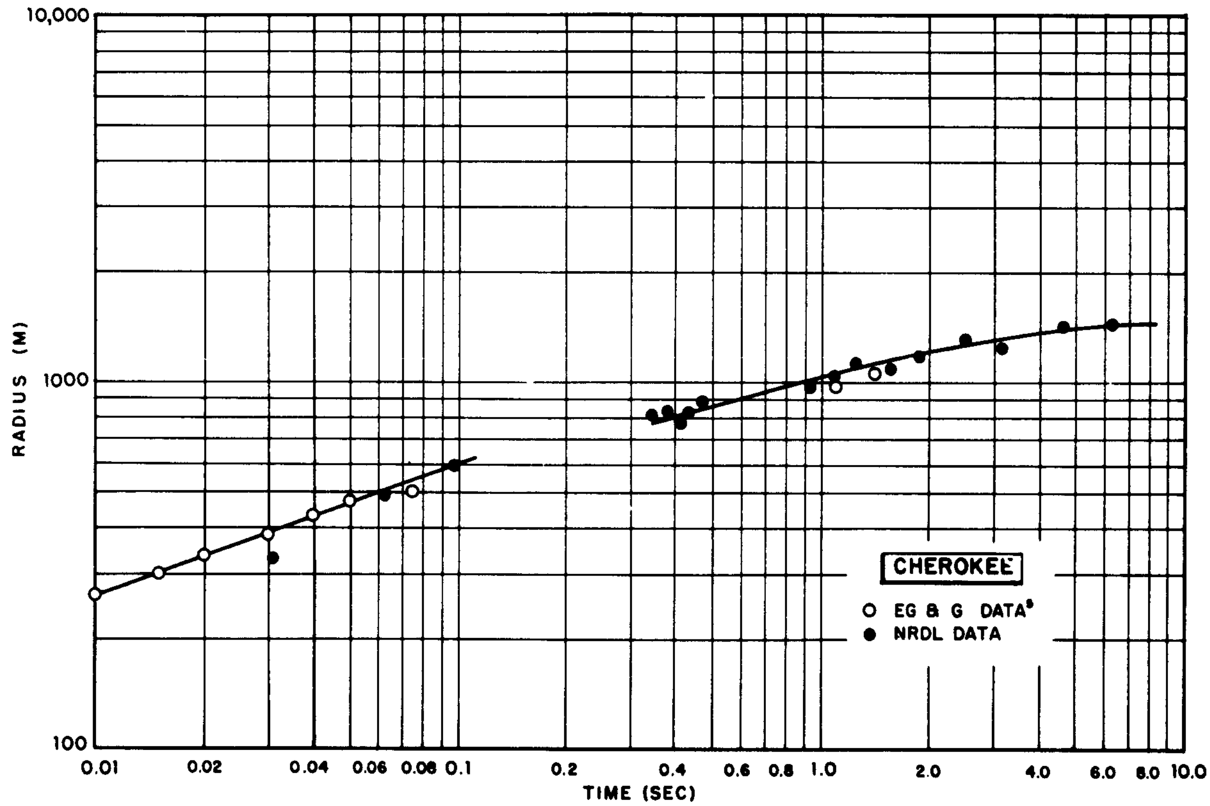


Figure 3.22 Shot Cherokee fireball radius versus time.

SECRET

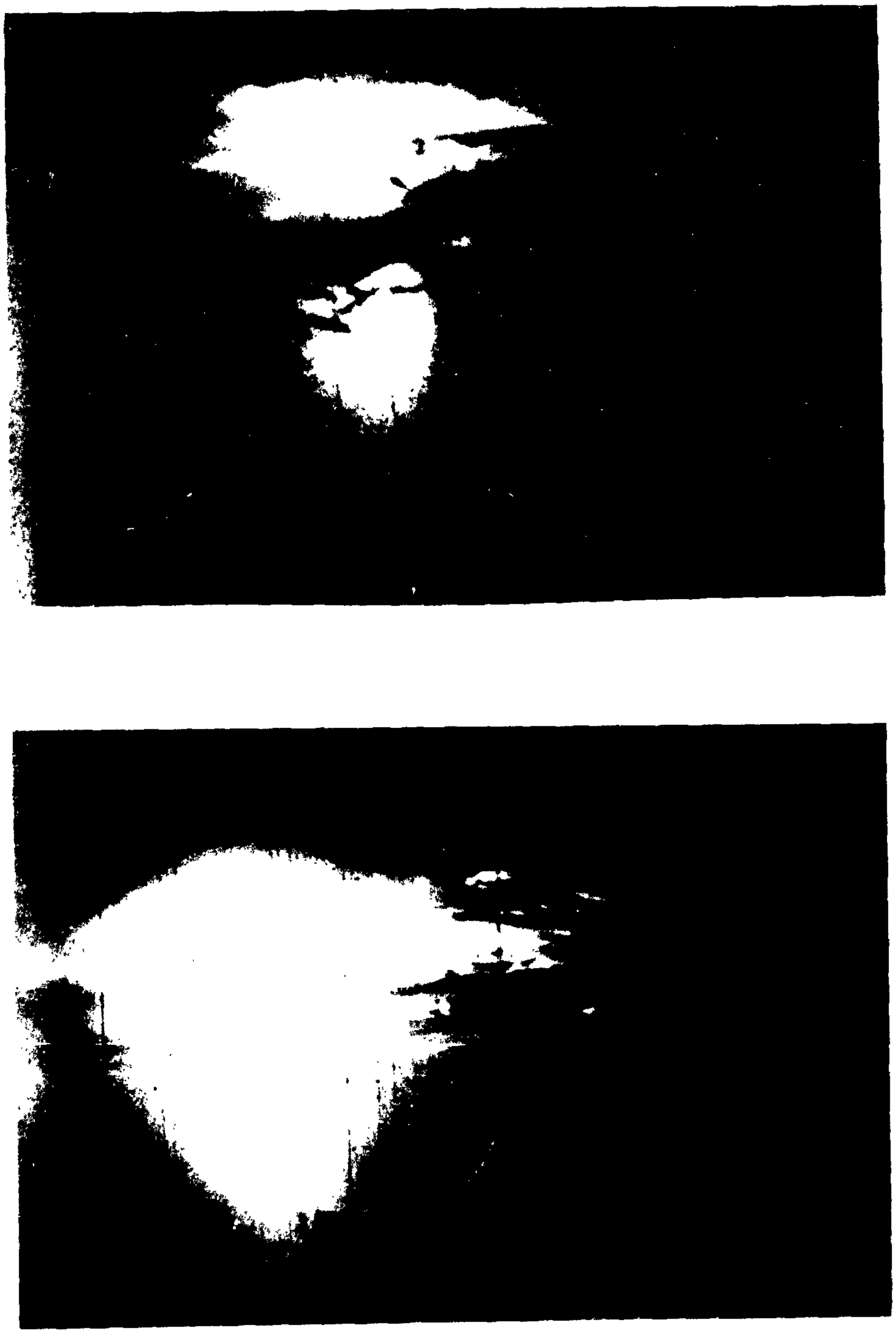


Figure 3.23 Shot Cherokee from F-84,(top) 0.47 sec and (bottom) 1.25 sec.

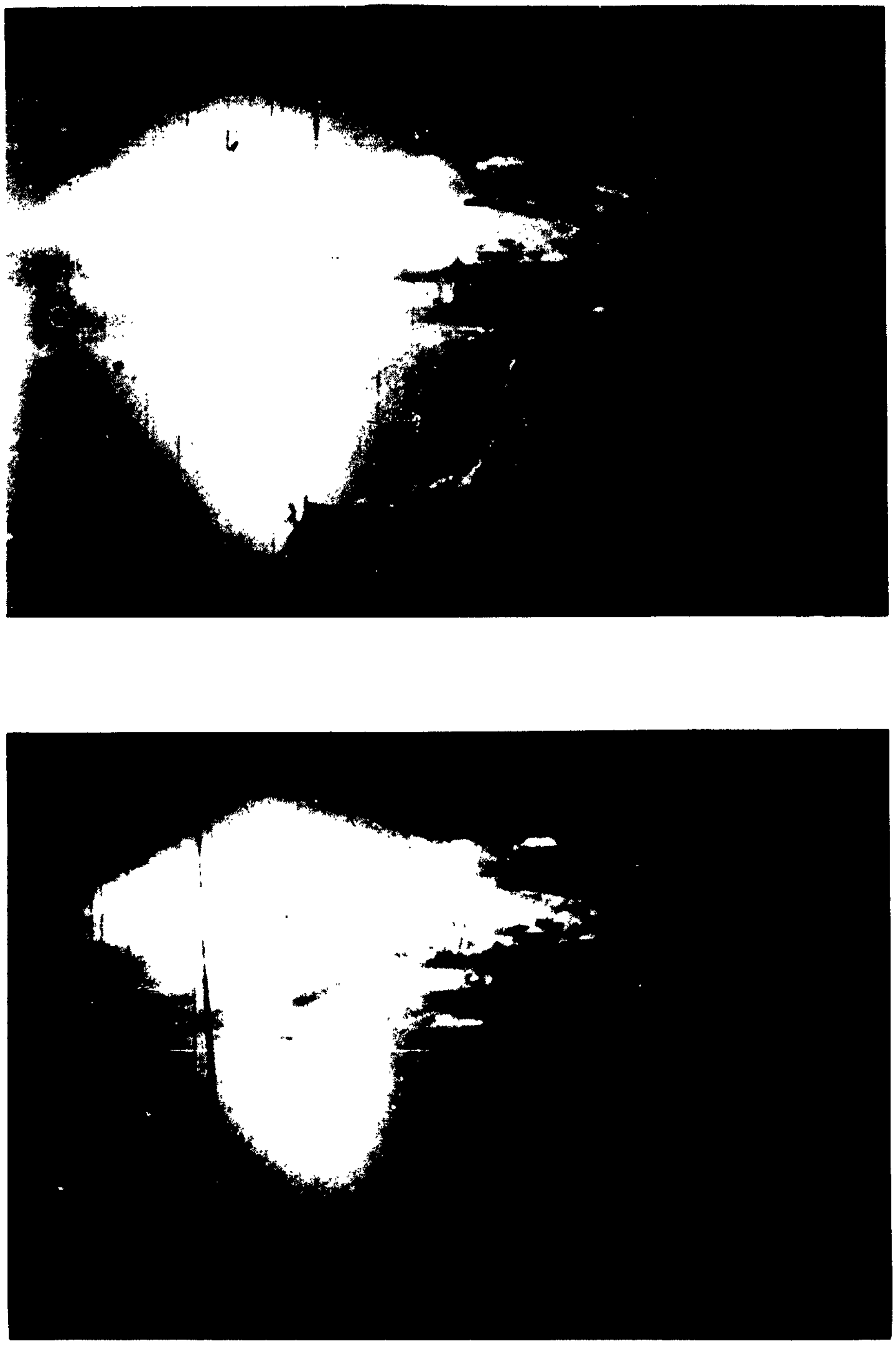


Figure 3.24 Shot Cherokee from F-84,(top) 1.875 sec and (bottom) 2.50 sec.

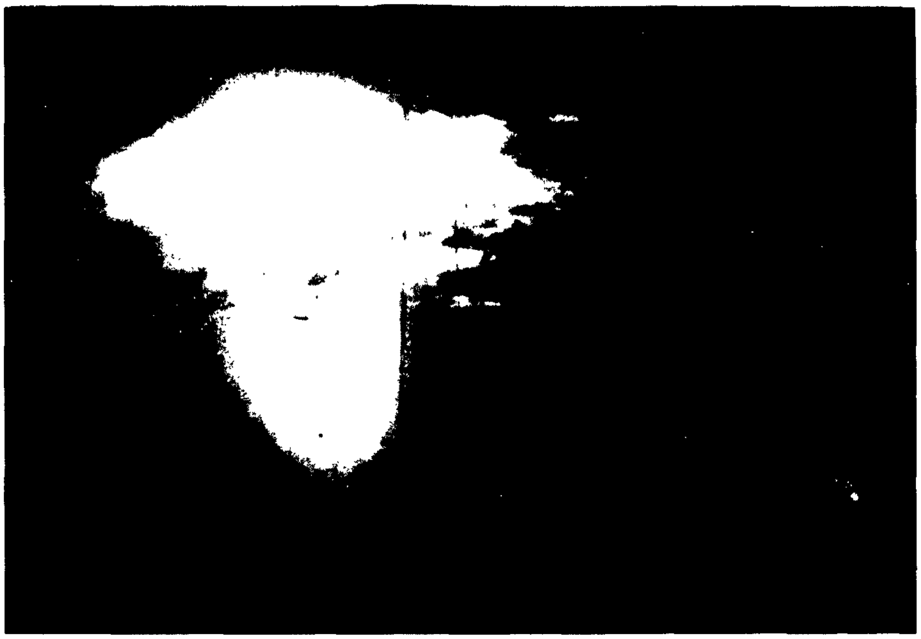


Figure 3.25 Shot Cherokee from F-84, (top) 3.13 sec and (bottom) 4.67 sec.

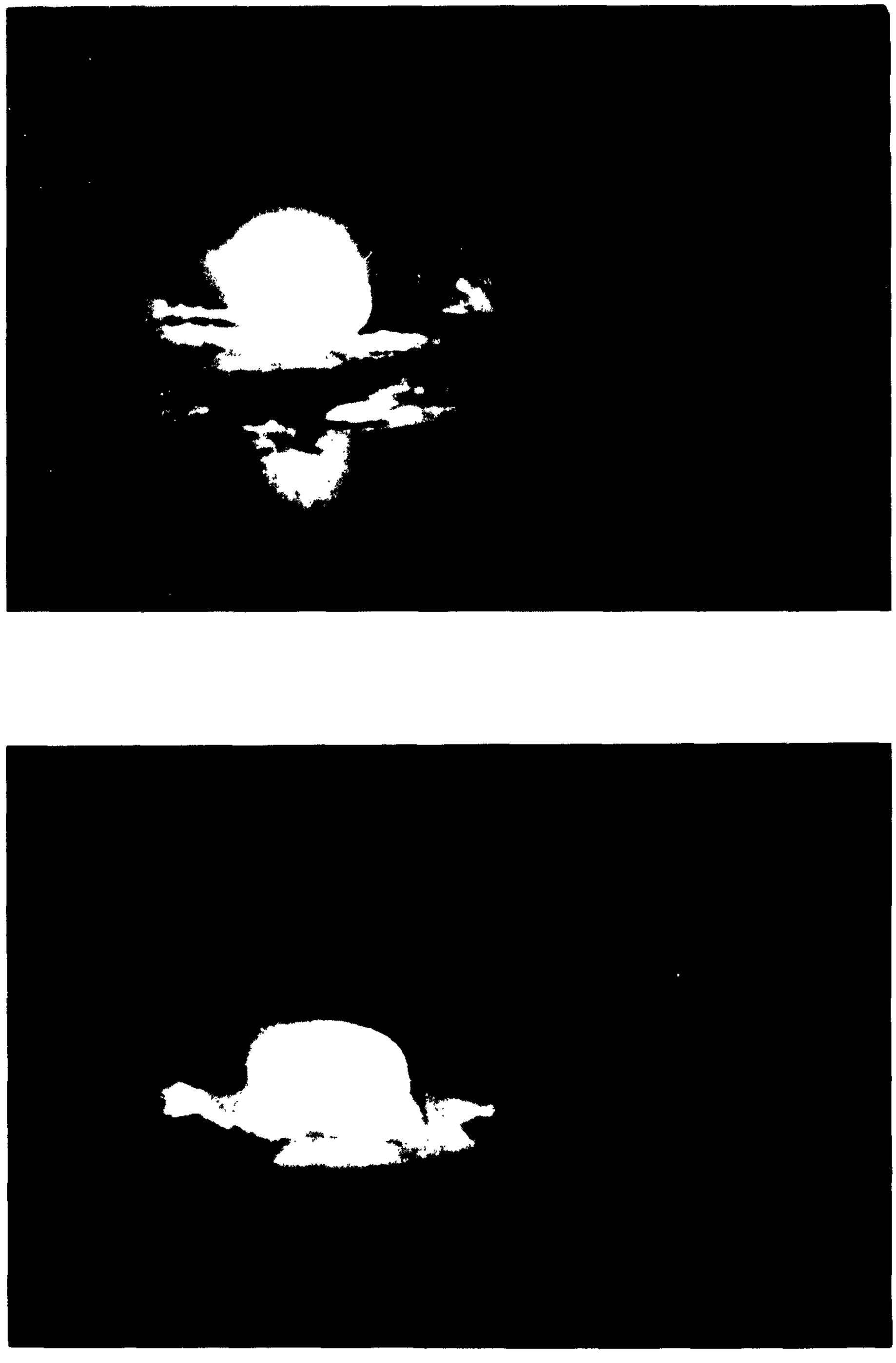


Figure 3.26 Shot Cherokee from F-84, (top) 6.25 sec and (bottom) 9.9 sec.

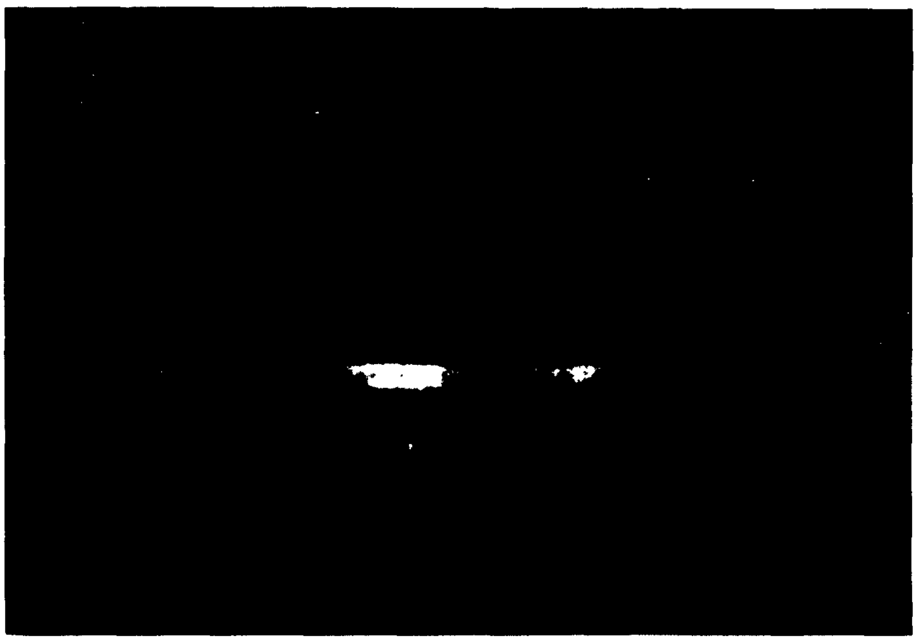


Figure 3.27 Shot Cherokee from F-84, (top) 15.8 sec and (bottom) 25.7 sec.

SECRET

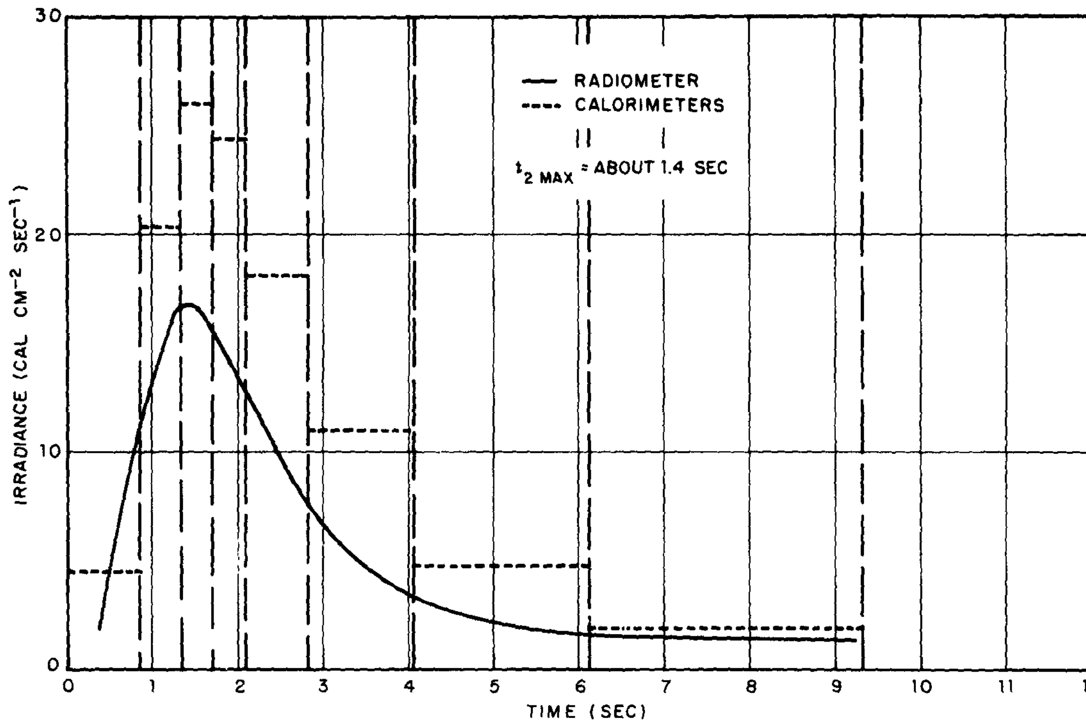


Figure 3.28 Shot Cherokee irradiance versus time, Site Dog.

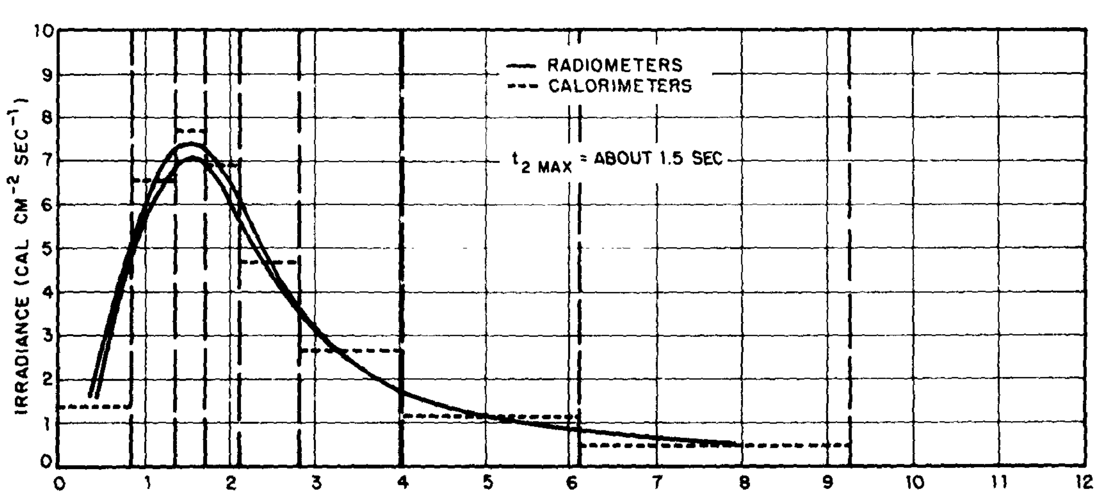


Figure 3.29 Shot Cherokee irradiance versus time, Site George.

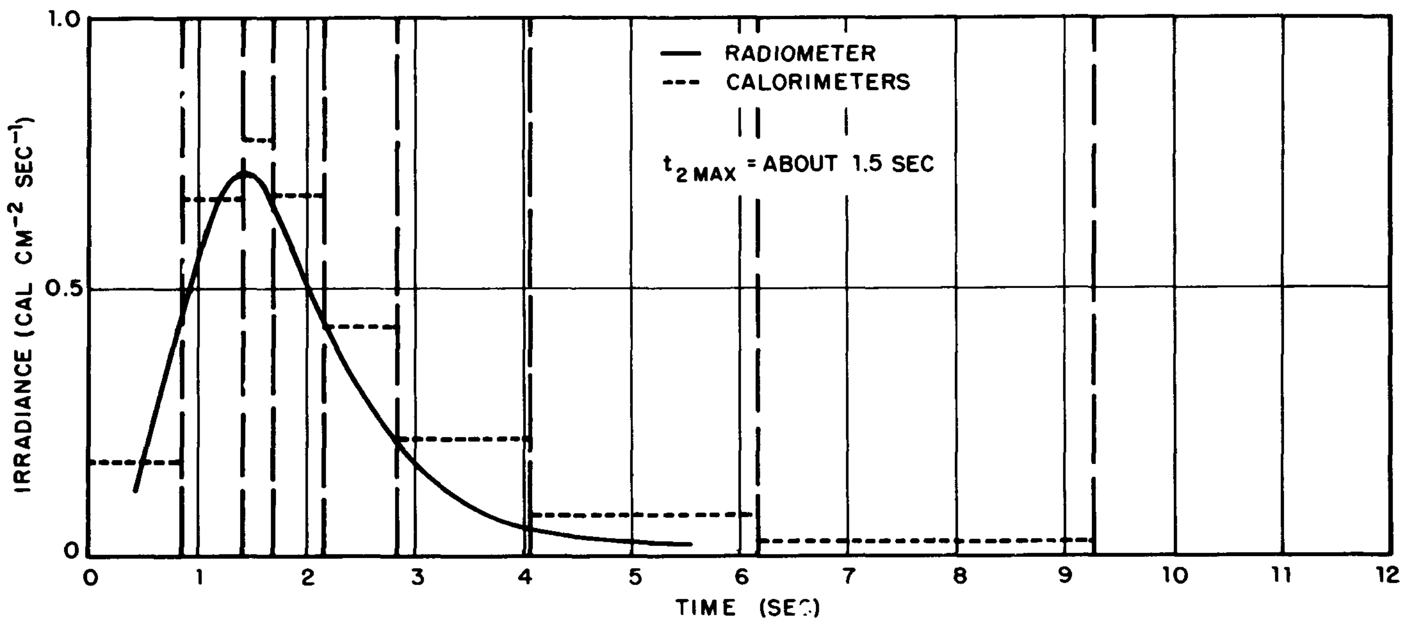


Figure 3.30 Shot Cherokee irradiance versus time, Site How.

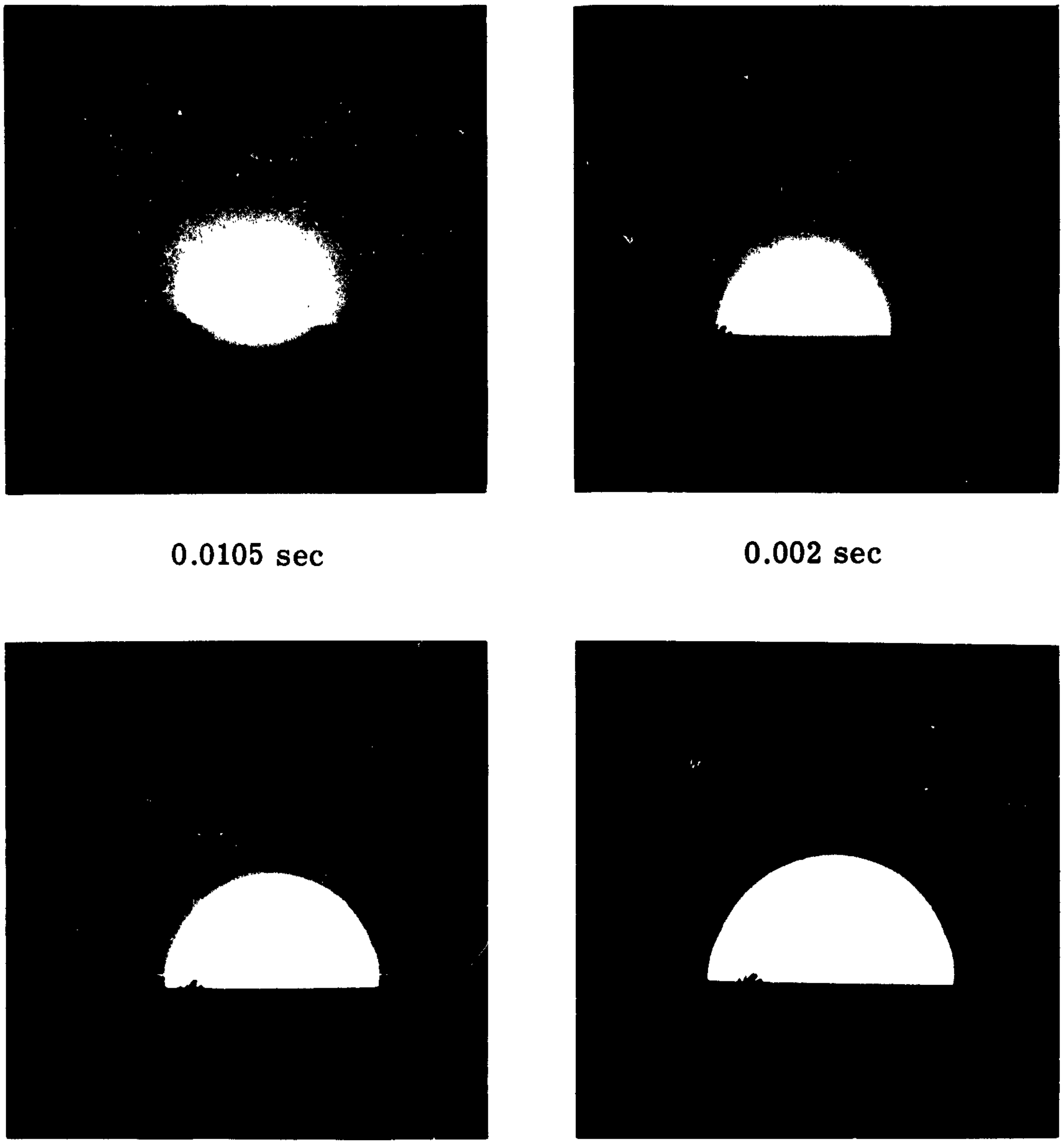
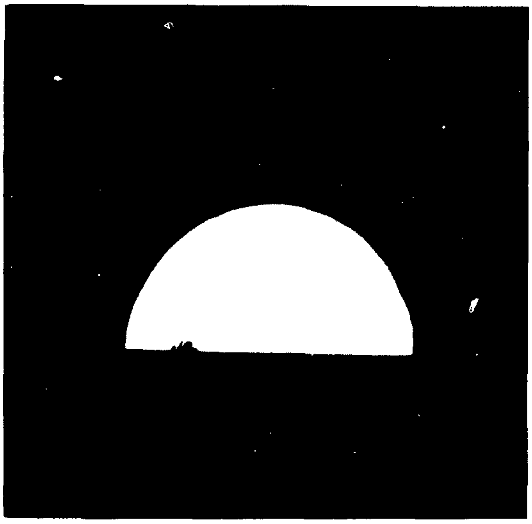
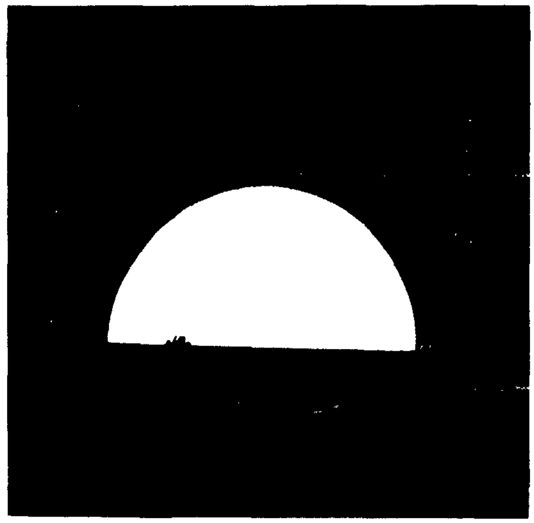


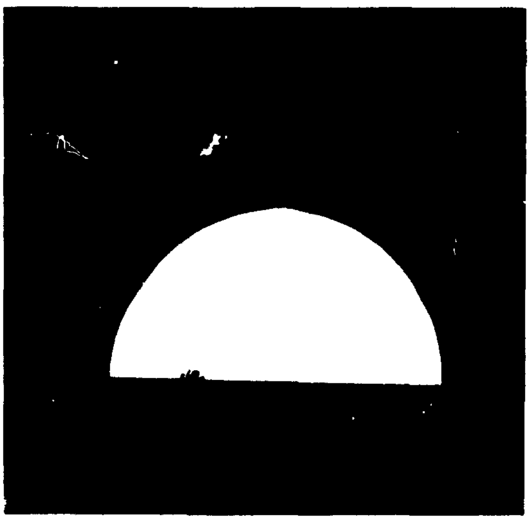
Figure 3.31 Shot Zuni from Site William.



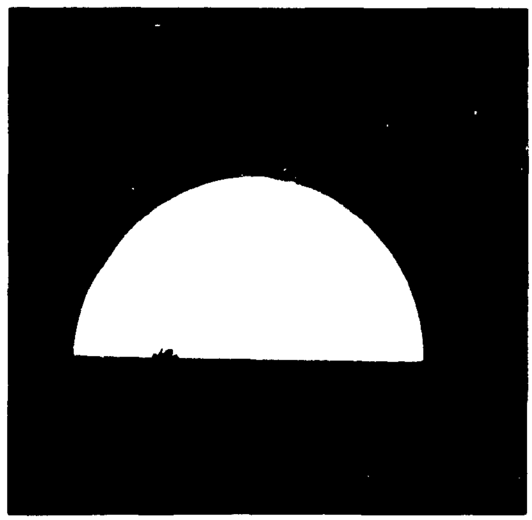
0.0595 sec



0.0435 sec



0.0765 sec



0.0650 sec

Figure 3.32 Shot Zuni from Site William.

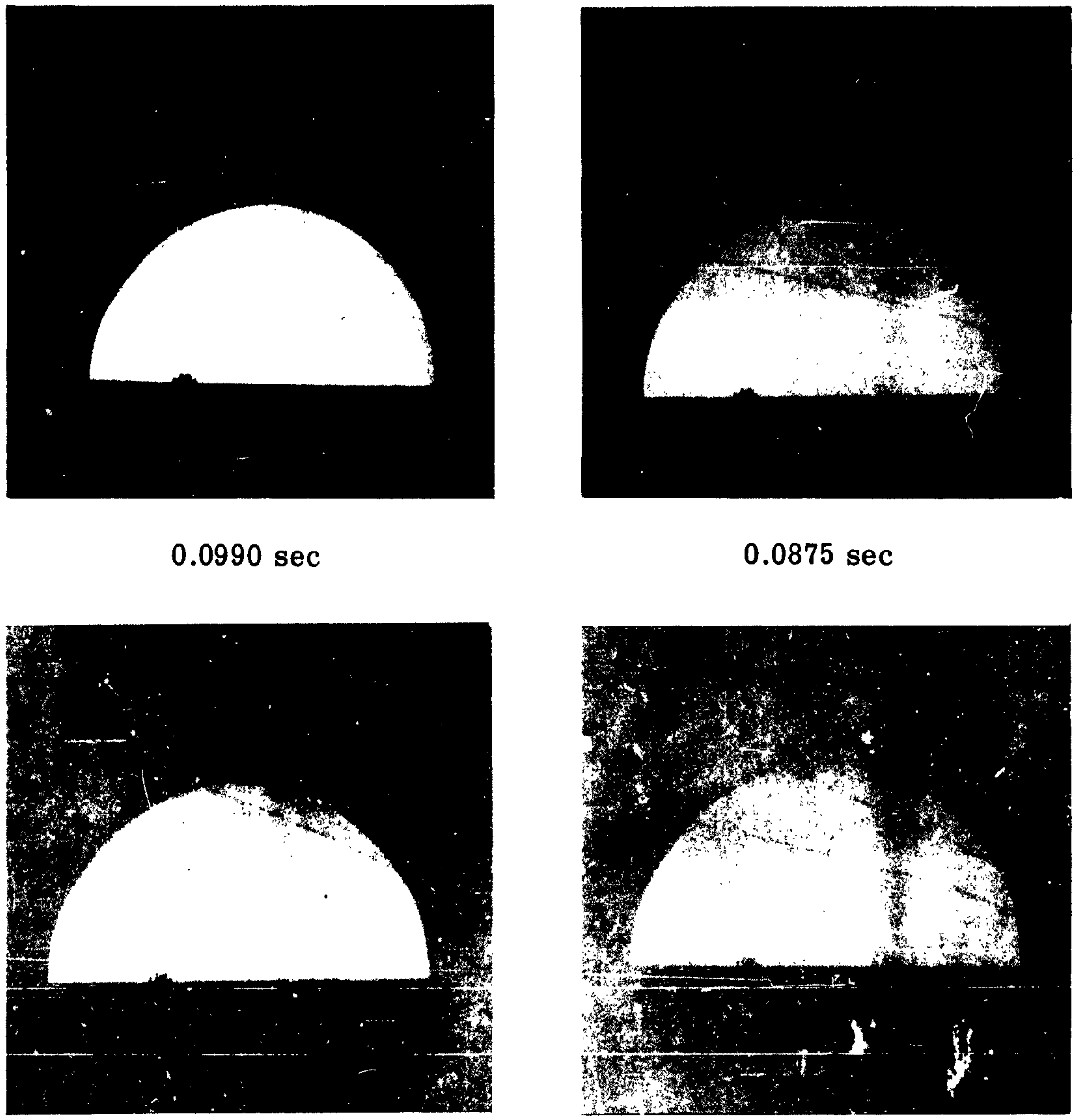


Figure 3.33 Shot Zuni from Site William.

0.28 sec

0.44 sec

Figure 3.34 Shot Zuni from Site William.

1.20 sec

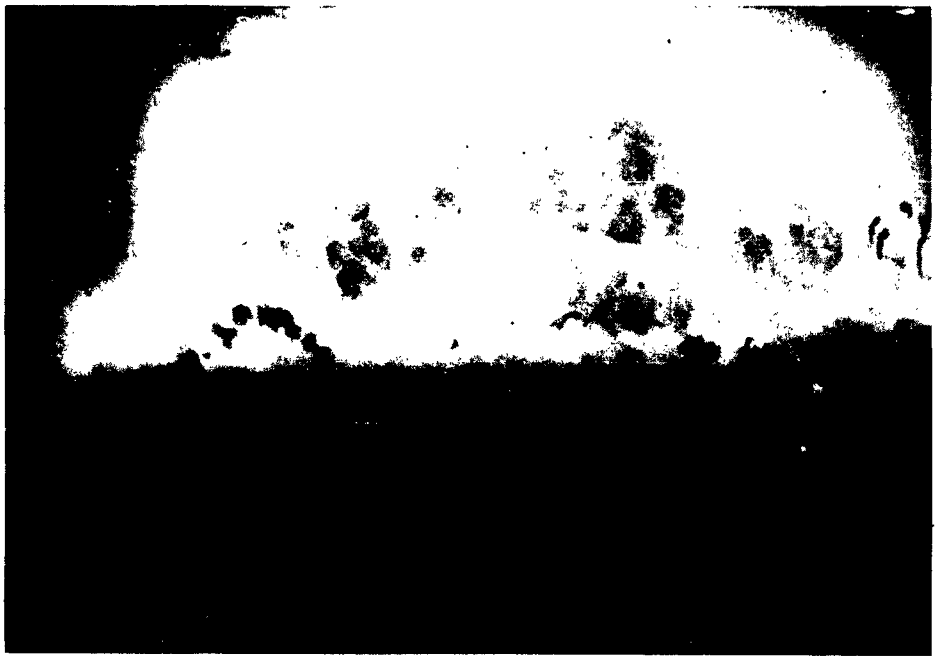
1.75 sec

Figure 3.35 Shot Zuni from Site William.

2.27 sec

3.05 sec

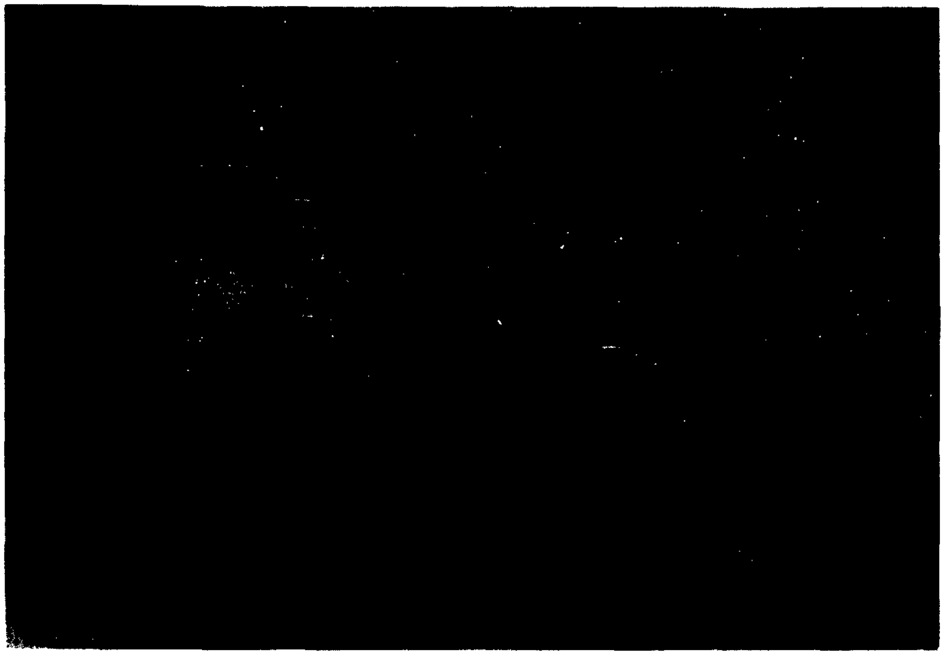
Figure 3.36 Shot Zuni from Site William.



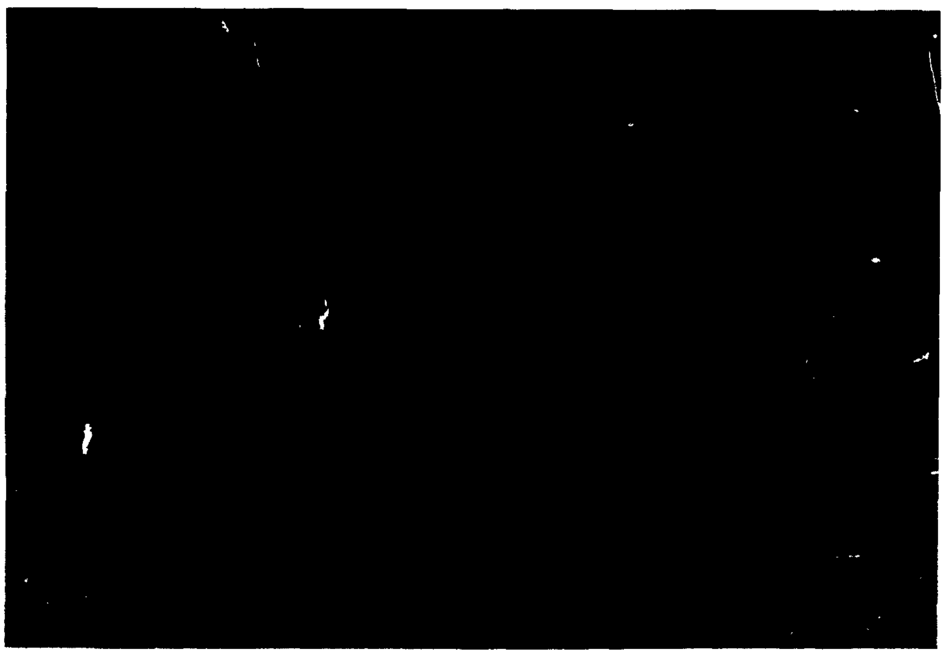
4.35 sec

6.50 sec

Figure 3.37 Shot Zuni from Site William.



9.30 sec



11.0 sec

Figure 3.38 Shot Zuni from Site William.

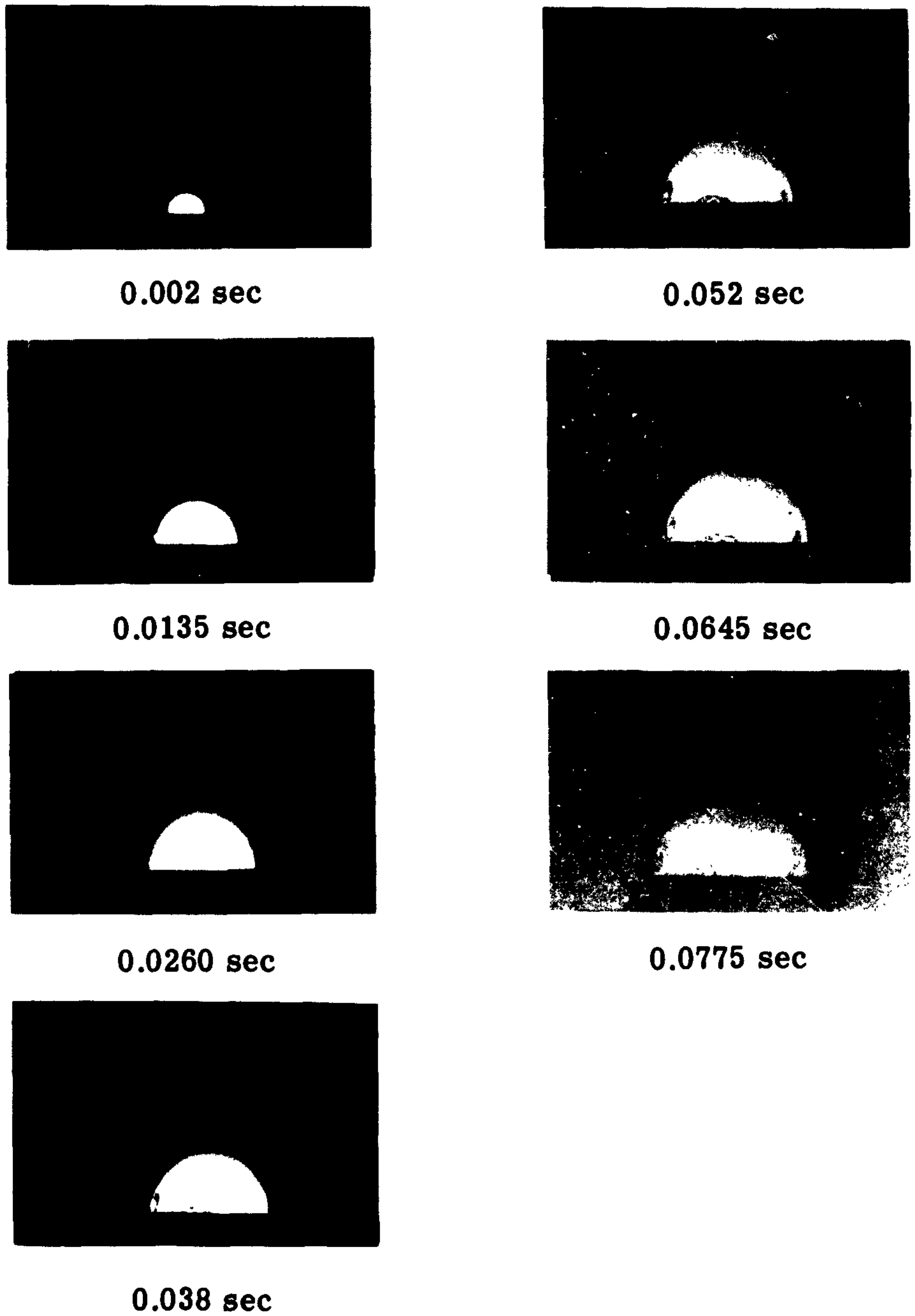
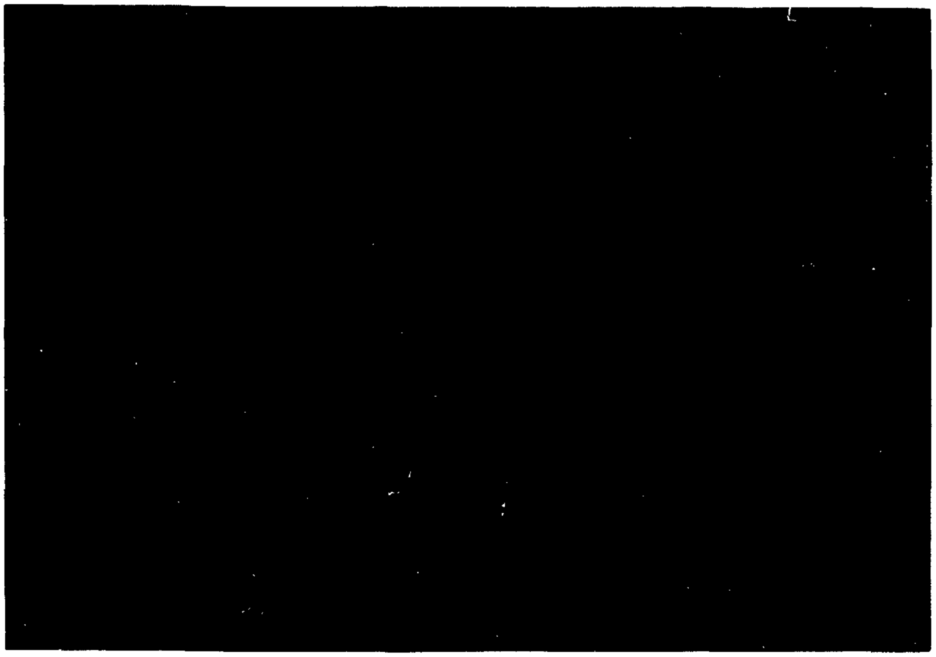


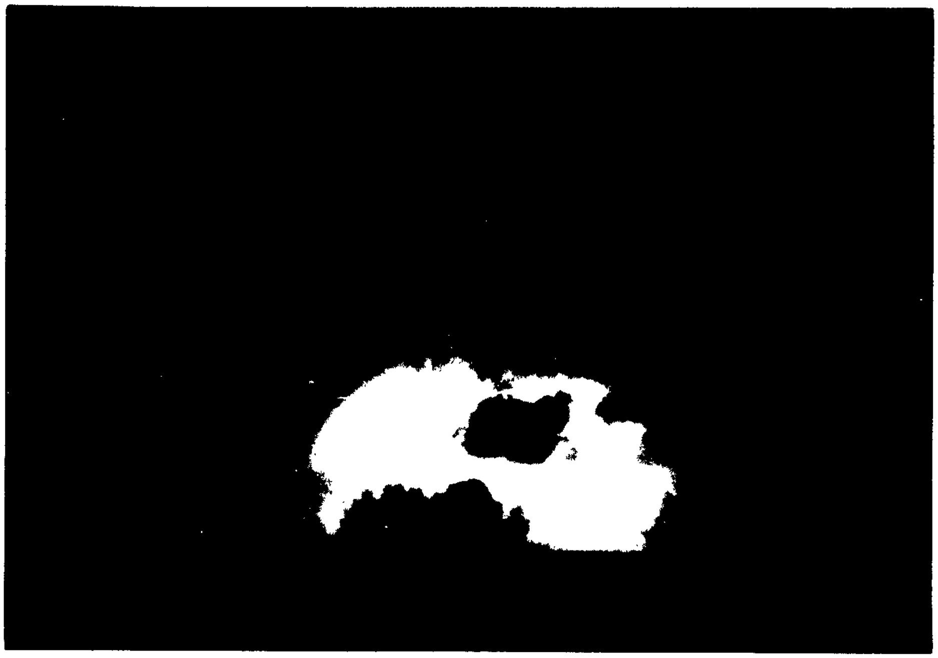
Figure 3.39 Shot Zuni from Site Nan.



0.48 sec

1.135 sec

Figure 3.40 Shot Zuni from Site Nan.



1.95 sec

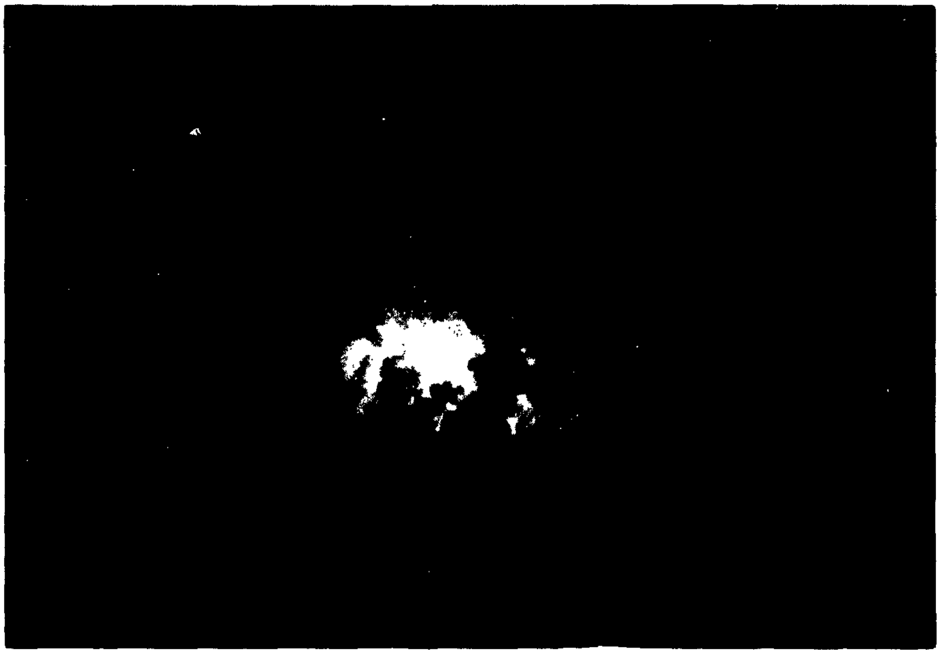
2.60 sec

Figure 3.41 Shot Zuni from Site Nan.

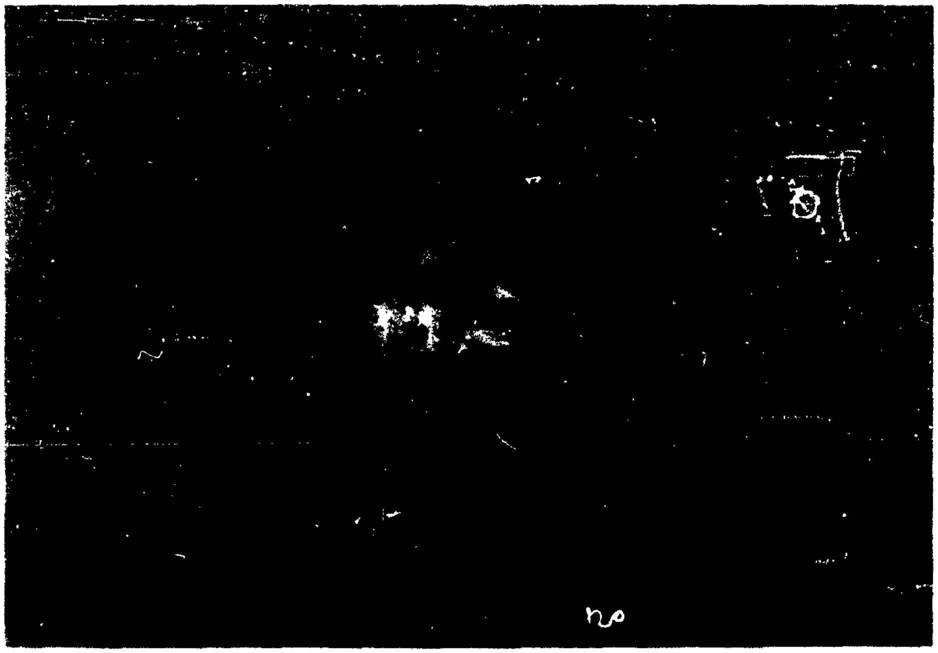
3.40 sec

4.80 sec

Figure 3.42 Shot Zuni from Site Nan.



7.0 sec



9.6 sec

Figure 3.43 Shot Zuni from Site Nan.

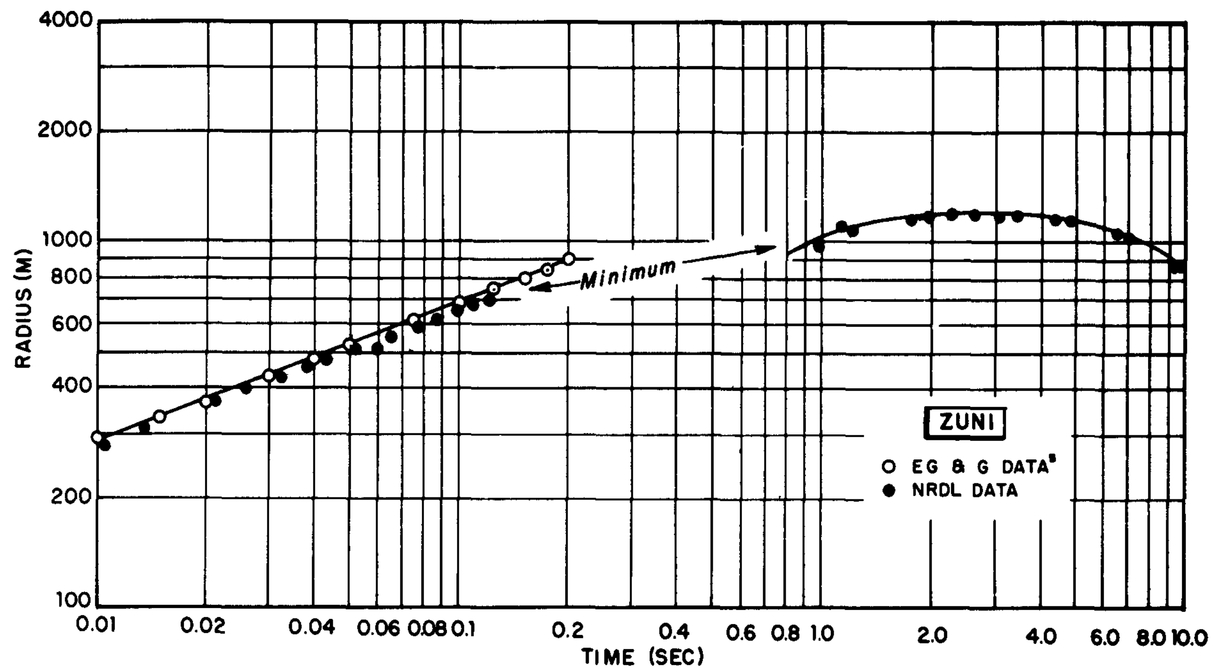


Figure 3.44 Shot Zuni fireball radius versus time.

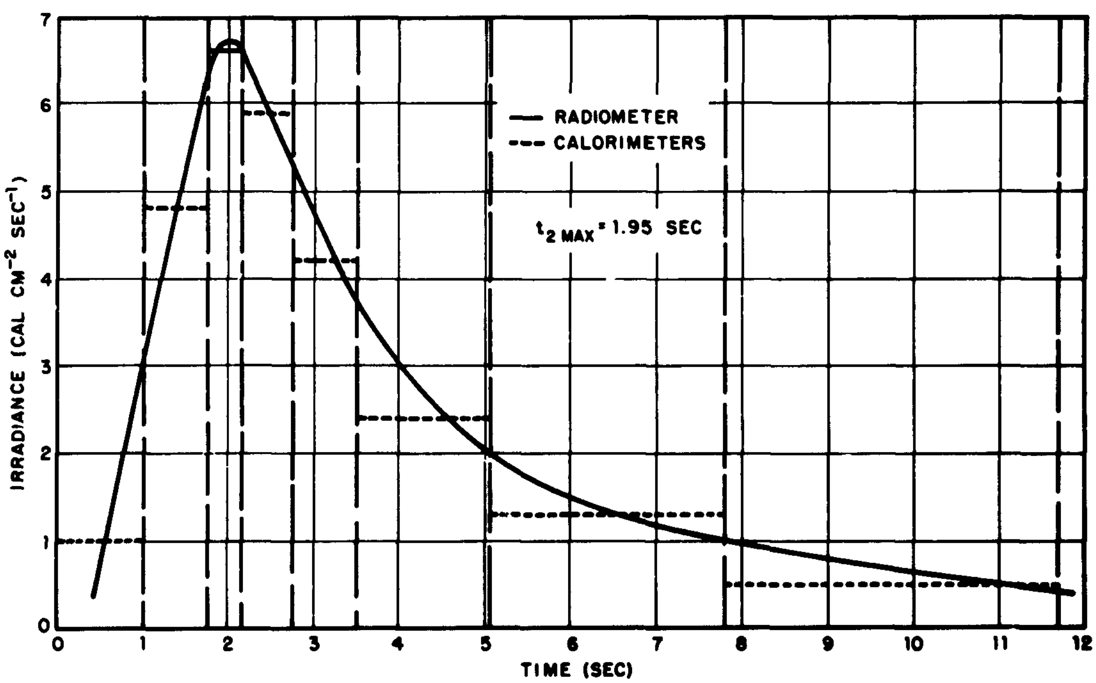


Figure 3.45 Shot Zuni irradiance versus time, Site William.

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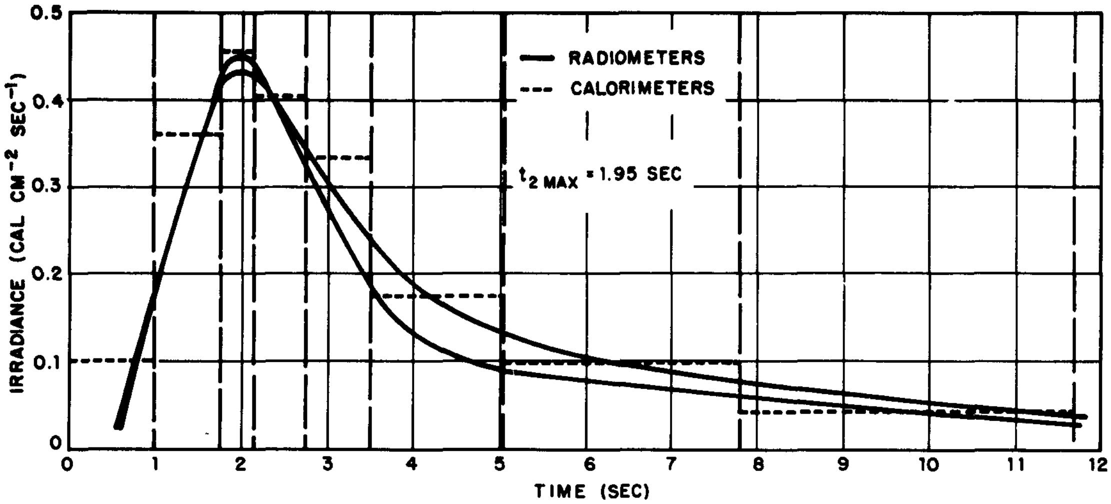

Figure 3.46 Shot Zuni irradiance versus time, Site Nan, 42-foot tower.

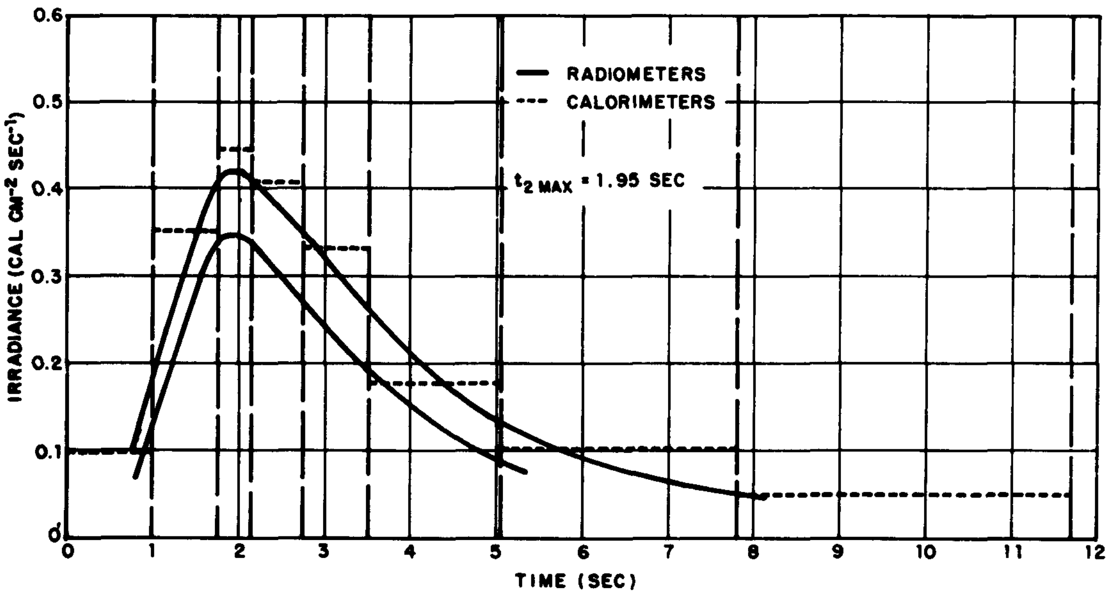

Figure 3.47 Shot Zuni irradiance versus time, Site Nan, 200-foot tower.

Chapter 4
DISCUSSION

The experimental measurements were generally successful from an instrumental point of view. Data sufficient to attempt a thermal analysis were obtained from Shots Lacrosse and Zuni; but the lack of photographic data for Shot Cherokee, due to the positioning error, makes a thermal analysis all but impossible for this detonation. The accuracy of the calorimetric data is better than plus or minus 5 percent for the standard 90-degree-field-of-view instruments. The accuracy of the photographic measurements cannot be assessed directly, but the values compare favorably with similar measurements by EG&G (Reference 5).

The interpretation of thermal measurements made at the EPG is a complex undertaking. The simple formulas and reasoning that can be applied to small air bursts in the clear Nevada skies are not applicable to the surface bursts in the cloudy skies of the Pacific. Factors such as burst geometry and obscuration may be more significant in determining the thermal inputs than is the yield of the nuclear device itself.

The data that have been presented in Chapter 3 are observed data, and only calibration factors and instrumental corrections have been applied. The analysis presented in this chapter is based on the interpretation and judgment of the authors. The reader is encouraged to perform his own analysis in the event that he prefers other methods of interpretation.

The general methods of thermal analysis are presented in detail in Reference 6. This semitheoretical treatment requires some 50 pages of derivations and discussions. The presentation that follows is sufficient to give the reader an indication of the methods employed, but does not cover the reasoning behind these methods, except in a general manner. The interested reader is requested to consult Reference 6 for further details and, also, for a more-complete treatment of the data taken during Operation Redwing.

The thermal yield of a bomb may be defined as the best estimate of the total energy radiated by the bomb in the form of thermal radiation, i.e., radiation for which the wave length is between 2,000 Å and 10 μ. In the case of an air burst, where the fireball is assumed to radiate equally in all directions, the thermal yield is obtained by correcting the measured energy value by dividing by the filter transmission and the atmospheric transmission and multiplying by $4D^2$, where D is the slant range in centimeters. If the fireball photography shows the instrument to be poorly aligned, a cosine correction must be made to correct for the variation of instrumental sensitivity with angle. If the fireball photography shows that clouds cover a portion of the fireball as seen by the calorimeter, then an estimate of cloud attenuation must be made and the calorimeter reading increased accordingly. Since filter corrections and atmospheric transmission are dependent upon the spectral distribution of the radiation from the source, which varies with time, the entire analysis must be carried out as a function of time.

The thermal yield can then be expressed as:

$$Q = 4\pi D^2 \sum_j \left(\frac{\beta_i \Delta_q}{\beta_w T}\right)_j \tag{4.1}$$

Where: β_i = the idealized area of the fireball, without obscuration, for the j'th time interval

β_w = the estimated area of the fireball, for the j'th time interval, after the area of clouds and opaque objects have been deducted

Δq = the measured value of energy received during the j'th time interval (cal/cm^2)

T = the transmission of the instrument filter and the atmosphere (a combined correction) as estimated for the j'th time interval

D = the slant range in centimeters

The areas β_i and β_w are measured directly on the fireball photograph by use of a planimeter and must both be in the same units. The estimation of the area of obscuring clouds and opaque objects is subject to the investigator's judgment. Representative fireball photographs have thus been made a permanent part of this report, so the reader can judge for himself as to the probable accuracy of the final results.

Atmospheric transmission measurements, directly applicable to the experiment reported herein, are not available. The authors thus chose values which seemed reasonable to them on the basis of their previous experience. The transmission of the quartz filters is 92 per-

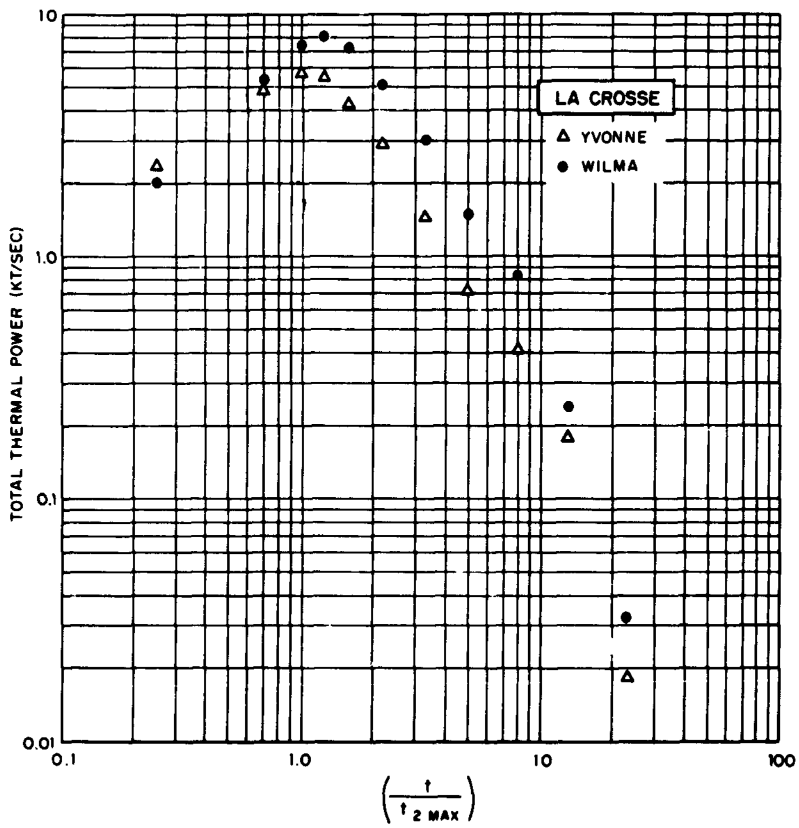

Figure 4.1 Total thermal power versus time, Shot Lacrosse.

cent, except when the color temperature of the source is below 3,000 K. An estimated first approximation of source temperature was thus required to determine a filter correction.

In the case of a hemispherical fireball, the total radiating area of the fireball surface is half of that of a spherical fireball of the same radius. Similarly, the cross-sectional area of the fireball as seen by the observer, in the case of a hemispherical fireball, is one half of that as seen for a spherical fireball, as long as the observer is in the plane of the base of the hemispherical fireball. Since this was the case for the measurements quoted herein, Equation 4.1 also gives the thermal yield of surface bursts.

The thermal analyses for each station for each shot are presented in Tables 4.1 through

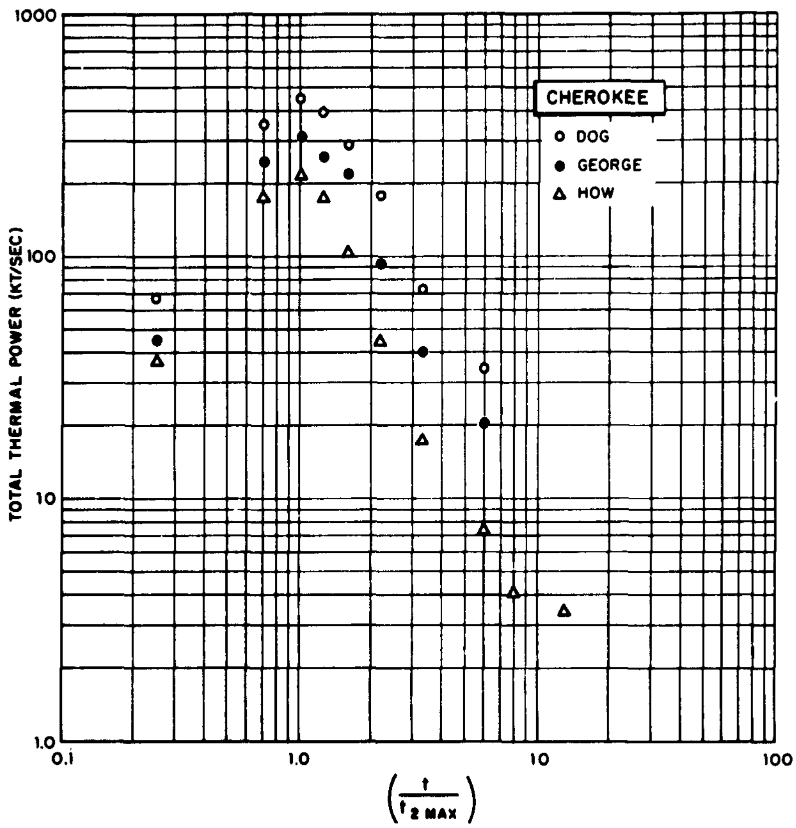

Figure 4.2 Total thermal power versus time, Shot Cherokee.

4.7. The total thermal power is obtained by dividing the thermal yield for each time interval by the length of the time interval. These values are plotted in Figures 4.1 through 4.3.

Tables 4.1 through 4.7 also include an estimated minimum power temperature, Ψ, which is defined by Stefan's law and was calculated from the formula:

$$\Psi_{\Delta t} = \sqrt[4]{\frac{\pi D^2 \frac{\Delta qm}{\Delta t}}{h \epsilon \beta_W T}} \tag{4.2}$$

Where: h = Stefan's constant (1.356×10^{-12} cal cm^{-2}sec^{-1}deg^{-4})

ϵ = the average emissivity of the fireball

Epsilon (ϵ) was chosen as 1.0, since its actual value is not known. This leads to a minimum value of power temperature.

Equation 4.2 will be immediately recognized as the well-known formula for the energy radiated by a flat-plate radiator, solved for the temperature.

The thermal partition (thermal yield divided by total yield) has also been calculated in each

TABLE 4.1 THERMAL ANALYSIS FOR SHOT LACROSSE, SITE YVONNE

Total Yield 39.5 Thermal Partition 2.72/39.5 = 0.094.

Time Interval Number	Δt Time Interval	Δq_m Measured Energy	1/cos θ Alignment Correction	Approximate First Temperature	T Total Transmission	Energy Correction	β_w Weighted Fireball Area	Ψ Power Temperature	β_i Idealized Fireball Area	g Geometric Factor	Geometric Correction	ΔQ Total Energy	ΣΔQ Thermal Yield	ΔQ/Δt Total Thermal Power
	sec	cal/cm²		K			10^8 cm²	K	10^8 cm²		10^{12} cm²	kt	kt	kt/sec
I	0.11	0.207	1.0	4600	0.68	0.304	4.52	5410	5.02	4.0	0.854	0.260	0.260	2.36
II	0.09	0.315	1.0	5400	0.71	0.443	7.20	5570	9.19	4.0	0.983	0.435	0.695	4.83
III	0.04	0.166	1.0	5700	0.71	0.234	8.52	5580	10.77	4.0	0.973	0.227	0.922	5.67
IV	0.07	0.262	1.0	5400	0.71	0.369	8.81	5400	11.87	4.0	1.037	0.383	1.305	5.47
V	0.09	0.262	1.0	5000	0.70	0.374	9.42	5000	12.48	4.0	1.019	0.381	1.686	4.23
VI	0.17	0.333	1.0	4500	0.67	0.497	10.1	4500	13.20	4.0	1.005	0.499	2.185	2.93
VII	0.31	0.305	1.0	4000	0.64	0.476	10.8	3770	13.39	4.0	0.954	0.454	2.639	1.46
VIII	0.44	0.196	1.0	3400	0.58	0.338	(11.0)	3150	(13.4)	4.0	0.937	0.317	2.956	0.720
IX	0.88	0.202	1.0	2900	0.52	0.388	(11.0)	2750	(13.4)	4.0	0.937	0.364	3.320	0.414
X	1.32	0.113	1.0	2500	0.45	0.251	(11.0)	2230	(13.4)	4.0	0.937	0.235	3.555	0.178
XI	3.08	0.025	1.0	2200	0.40	0.060	(11.0)	2240	(13.4)	4.0	0.937	0.056	3.611	0.018
XII	—	0.041	1.0	1900	0.34	0.121	(11.0)	—	(13.4)	4.0	0.937	0.113	3.724	—

TABLE 4.2 THERMAL ANALYSIS FOR SHOT LACROSSE, SITE WILMA

Total Yield 39.5. Thermal Partition 5.96/39.5 = 0.151.

Time Interval Number	Δt Time Interval	Δq_m Measured Energy	1/cos θ Alignment Correction	Approximate First Temperature	T Total Transmission	Energy Correction	β_w Weighted Fireball Area	Ψ Power Temperature	β_i Idealized Fireball Area	g Geometric Factor	Geometric Correction	ΔQ Total Energy	ΣΔQ Thermal Yield	ΔQ/Δt Total Thermal Power
	sec	cal/cm²		K			10^8 cm²	K	10^8 cm²		10^{12} cm²	kt	kt	kt/sec
I	0.11	0.057	1.0	4600	0.62	0.091	5.02	5200	5.02	4.0	2.418	0.220	0.220	2.00
II	0.09	0.127	1.0	5400	0.64	0.198	9.19	5710	9.19	4.0	2.418	0.479	0.699	5.31
III	0.04	0.079	1.0	5700	0.65	0.122	10.77	5950	10.77	4.0	2.418	0.295	0.994	7.37
IV	0.07	0.150	1.0	5400	0.64	0.234	11.87	5950	11.87	4.0	2.418	0.566	1.560	8.08
V	0.09	0.171	1.0	5000	0.63	0.271	12.48	5720	12.48	4.0	2.418	0.655	2.215	7.27
VI	0.17	0.220	1.0	4500	0.62	0.354	13.20	5160	13.20	4.0	2.418	0.856	3.071	5.03
VII	0.31	0.228	1.0	4000	0.59	0.386	13.39	4500	13.39	4.0	2.418	0.933	4.004	3.01
VIII	0.44	0.144	1.0	3400	0.53	0.271	(13.4)	3780	(13.4)	4.0	2.418	0.655	4.659	1.49
IX	0.88	0.142	1.0	2900	0.47	0.302	(13.4)	3270	(13.4)	4.0	2.418	0.730	5.389	0.830
X	1.32	0.052	1.0	2500	0.41	0.127	(13.4)	2370	(13.4)	4.0	2.418	0.307	5.696	0.233
XI	3.08	0.012	1.0	2200	0.36	0.033	(13.4)	2450	(13.4)	4.0	2.418	0.080	5.776	0.026
XII	—	0.024	1.0	1900	0.31	0.077	—	—	—	4.0	2.418	0.186	5.962	—

TABLE 4.3 THERMAL ANALYSIS FOR SHOT CHEROKEE, SITE DOG

Total Yield 3.8 Mt. Thermal Partition 1272/3800 = 0.334.

Time Interval Number	Δt Time Interval	Δq_m Measured Energy	$1/\cos\theta$ Alignment Correction	Approximate First Temperature	T Total Trans-mission	Energy Correction	β_w Weighted Fireball Area	Ψ Power Temperature	β_i Idealized Fireball Area	g Geometric Factor	Geometric Correction	ΔQ Total Energy	$\Sigma\Delta Q$ Thermal Yield	$\Delta Q/\Delta t$ Total Thermal Power
	sec	cal/cm^2		K			cm^2	K	10^{10} cm^2		10^{12} cm^2	kt	kt	kt/sec
I	0.78	3.06	1.19	5000	0.56	6.50	—	4970	2.01	4.0	8.12	52.8	52.8	67.6
II	0.62	12.16	1.19	6500	0.54	26.80	—	6530	3.46	4.0	8.12	217.6	270.4	350
III	0.31	7.54	1.19	6900	0.52	17.25	—	6800	4.01	4.0	8.12	140.0	410.4	452
IV	0.46	10.25	1.19	6400	0.54	22.58	—	6330	4.52	4.0	8.12	183.3	593.7	398
V	0.62	10.24	1.19	5900	0.55	22.15	—	5700	4.99	4.0	8.12	179.9	773.6	290
VI	1.24	12.93	1.19	5000	0.56	27.47	—	4940	5.56	4.0	8.12	223.1	996.7	179
VII	2.17	8.40	1.19	3800	0.51	19.60	—	3770	6.16	4.0	8.12	159.2	1155.9	73.3
VIII	3.10	5.04	1.19	3100	0.45	13.32	—	3080	6.60	4.0	8.12	108.2	1264.1	34.8
IX	—	0.30	1.19	2500	0.37	0.964	—	—	—	4.0	8.12	7.83	1271.9	—

TABLE 4.4 THERMAL ANALYSIS FOR SHOT CHEROKEE, SITE GEORGE

Total Yield 3.8 Mt. Thermal Partition 780/3800 = 0.205

Time Interval Number	Δt Time Interval	Δq_m Measured Energy	$1/\cos\theta$ Alignment Correction	Approximate First Temperature	T Total Trans-mission	Energy Correction	β_w Weighted Fireball Area	Ψ Power Temperature	β_i Idealized Fireball Area	g Geometric Factor	Geometric Correction	ΔQ Total Energy	$\Sigma\Delta Q$ Thermal Yield	$\Delta Q/\Delta t$ Total Thermal Power
	sec	cal/cm^2		K			cm^2	K	10^{10} cm^2		10^{13} cm^2	kt	kt	kt/sec
I	0.78	0.931	1.075	5000	0.495	2.021	—	4520	2.01	4.0	1.76	35.6	35.6	45.6
II	0.62	3.738	1.075	6500	0.465	8.639	—	6020	3.46	4.0	1.76	152.0	187.6	245
III	0.31	2.215	1.075	6900	0.445	5.350	—	6100	4.01	4.0	1.76	94.2	281.8	304
IV	0.46	2.910	1.075	6400	0.470	6.655	—	5680	4.52	4.0	1.76	117.1	398.9	254
V	0.62	2.686	1.075	5900	0.485	5.953	—	4970	4.99	4.0	1.76	104.8	503.7	169
VI	1.24	3.075	1.075	5000	0.495	6.678	—	4210	5.56	4.0	1.76	117.5	621.2	94.7
VII	2.17	2.123	1.075	3800	0.465	4.908	—	3300	6.16	4.0	1.76	86.4	707.6	39.8
VIII	3.10	1.404	1.075	3100	0.420	3.593	—	2750	6.60	4.0	1.76	63.2	770.8	20.3
IX	—	0.171	1.075	2500	0.350	0.525	—	—	—	4.0	1.76	9.2	780.0	—

TABLE 4.5 THERMAL ANALYSIS FOR SHOT CHEROKEE, SITE HOW

Total Yield 3.8 Mt. Thermal Partition 562/3800 = 0.148.

Time Interval Number	Δt Time Interval	Δq_m Measured Energy	$1/\cos\theta$ Alignment Correction	Approximate First Temperature	T Total Transmission	Energy Correction	β_w Weighted Fireball Area	Ψ Power Temperature	β_i Idealized Fireball Area	g Geometric Factor	Geometric Correction	ΔQ Total Energy	$\Sigma\Delta Q$ Thermal Yield	$\Delta Q/\Delta t$ Total Thermal Power
	sec	cal/cm^2		K			cm^2	K	10^{10} cm^2		10^{13} cm^2	kt	kt	kt/sec
I	0.78	0.113	1.02	5000	0.335	0.344	—	4280	2.01	4.0	8.32	28.6	28.6	36.7
II	0.62	0.384	1.02	6500	0.300	1.306	—	5530	3.46	4.0	8.32	108.6	137.2	175
III	0.31	0.224	1.02	6900	0.285	0.802	—	5600	4.01	4.0	8.32	66.7	203.9	215
IV	0.46	0.283	1.02	6400	0.300	0.962	—	5160	4.52	4.0	8.32	80.0	283.9	173
V	0.62	0.237	1.02	5900	0.315	0.767	—	4420	4.99	4.0	8.32	63.8	347.7	103
VI	1.24	0.224	1.02	5000	0.335	0.668	—	3500	5.56	4.0	8.32	55.6	403.3	44.8
VII	2.17	0.150	1.02	3800	0.340	0.450	—	2670	6.16	4.0	8.32	37.4	404.7	17.3
VIII	3.10	0.083	1.02	3100	0.310	0.273	—	2125	6.60	4.0	8.32	22.7	463.4	7.32
IX	6.20	0.078	1.02	2500	0.265	0.300	—	—	—	4.0	8.32	25.0	488.4	4.03
X	9.30	0.082	1.02	2000	0.220	0.380	—	—	—	4.0	8.32	31.6	520.0	3.39
XI	—	0.090	1.02	1700	0.180	0.510	—	—	—	4.0	8.32	42.4	562.4	—

TABLE 4.6 THERMAL ANALYSIS FOR SHOT ZUNI, SITE WILLIAM

Total Yield 3.5 Mt. Thermal Partition 0.602/3.5 = 0.172.

Time Interval Number	Δt Time Interval	Δq_m Measured Energy	$1/\cos\theta$ Alignment Correction	Approximate First Temperature	T Total Transmission	Energy Correction	β_w Weighted Fireball Area	Ψ Power Temperature	β_i Idealized Fireball Area	g Geometric Factor	Geometric Correction	ΔQ Total Energy	$\Sigma\Delta Q$ Thermal Yield	$\Delta Q/\Delta t$ Total Thermal Power
	sec	cal/cm^2		K			10^{10} cm^2	K	10^{10} cm^2		10^{13} cm^2	kt	kt	kt/sec
I	0.98	0.885	1.0	4200	0.51	1.74	0.953	4500	1.06	4.0	1.33	23.1	23.1	23.4
II	0.78	3.511	1.0	5700	0.52	6.75	1.84	5680	1.93	4.0	1.26	85.1	108.2	108
III	0.39	2.367	1.0	6000	0.52	4.55	2.14	5890	2.18	4.0	1.22	55.5	163.7	143
IV	0.58	3.150	1.0	5700	0.52	6.05	2.17	5640	2.22	4.0	1.23	74.4	238.1	128
V	0.78	3.058	1.0	5300	0.53	5.76	2.15	5250	2.20	4.0	1.23	70.8	308.9	91
VI	1.56	3.504	1.0	4700	0.525	6.67	2.00	4670	2.07	4.0	1.24	82.7	391.6	53
VII	2.73	3.359	1.0	4200	0.51	6.59	1.68	4220	1.73	4.0	1.23	81.1	472.7	29
VIII	3.90	1.810	1.0	3600	0.48	3.77	1.09	3740	1.13	4.0	1.24	46.7	519.4	12
IX	7.80	0.311	1.0	3200	0.45	0.691	—	—	—	4.0	1.23	8.50	527.9	1.1
X	11.7	0.340	1.0	2650	0.385	0.883	—	—	—	4.0	(1.23)	10.9	538.8	0.94
XI	27.3	1.259	1.0	2400	0.35	3.60	—	—	—	4.0	(1.23)	44.3	583.1	1.6
XII	—	0.357	1.0	1700	0.23	1.55	—	—	—	4.0	(1.23)	19.1	602.2	—

TABLE 4.7 THERMAL ANALYSIS FOR SHOT ZUNI, SITE NAN, 200-FOOT TOWER

Total Yield 3.5. Thermal Partition 0.729/3.5 = 0.208.

Time Interval Number	Δt Time Interval	Δq_m Measured Energy	1 cos θ Alignment Correction	Approximate First Temperature	T Total Trans-mission	Energy Correction	β_w Weighted Fireball Area	Ψ Power Temperature	β_i Idealized Fireball Area	g Geometric Factor	Geometric Correction	ΔQ Total Energy	$\Sigma\Delta Q$ Thermal Yield	$\Delta Q/\Delta t$ Total Thermal Power
	sec	cal/cm^2		K			10^{10} cm^2	K	10^{10} cm^2		10^{14} cm^2	kt	kt	kt/sec
I	0.98	0.084	1.0	4200	0.38	0.221	0.518	4570	1.06	4.0	1.12	24.8	24.8	25.3
II	0.78	0.249	1.0	5700	0.36	0.691	0.870	5750	1.93	4.0	1.22	84.3	109.1	108
III	0.39	0.160	1.0	6000	0.355	0.450	0.982	5850	2.18	4.0	1.21	54.4	163.5	139
IV	0.58	0.218	1.0	5700	0.36	0.605	0.996	5700	2.22	4.0	1.22	73.8	237.3	127
V	0.78	0.238	1.0	5300	0.37	0.643	0.990	5380	2.20	4.0	1.22	78.4	315.7	100
VI	1.56	0.254	1.0	4700	0.38	0.668	0.932	4630	2.07	4.0	1.22	81.5	397.2	52.2
VII	2.73	0.249	1.0	4200	0.38	0.655	0.797	4170	1.73	4.0	1.19	77.9	475.1	28.5
VIII	3.90	0.171	1.0	3600	0.36	0.475	0.561	3840	1.13	4.0	1.10	56.5	531.6	14.5
IX	7.80	0.182	1.0	3200	0.335	0.543	—	—	—	4.0	(1.05)	57.0	588.6	7.30
X	11.70	0.270	1.0	2650	0.29	0.931	—	—	—	4.0	(1.00)	93.1	681.7	7.95
XI	27.3	0.130	1.0	2400	0.27	0.481	—	—	—	4.0	(0.95)	45.7	727.4	1.7
XII	—	0.003	1.0	1700	0.19	0.016	—	—	—	4.0	(0.90)	1.4	728.8	—

case.

The color temperature of a fireball can be defined as the temperature of the black-body source whose spectral distribution most nearly matches that of the fireball at all wave lengths in the spectral region 3,650 Å to 4.2 μ.

The color temperature can be estimated for any short time interval by comparing the ratio of the change in readings of two calorimeters having different color filters. For this purpose the changes in readings of the calorimeters having Corning 3-69, 2-58, and 7-56 filters were compared with the change in reading of the calorimeter having a Corning 0-52 filters. The expected ratio of readings may be computed as a function of the temperature,

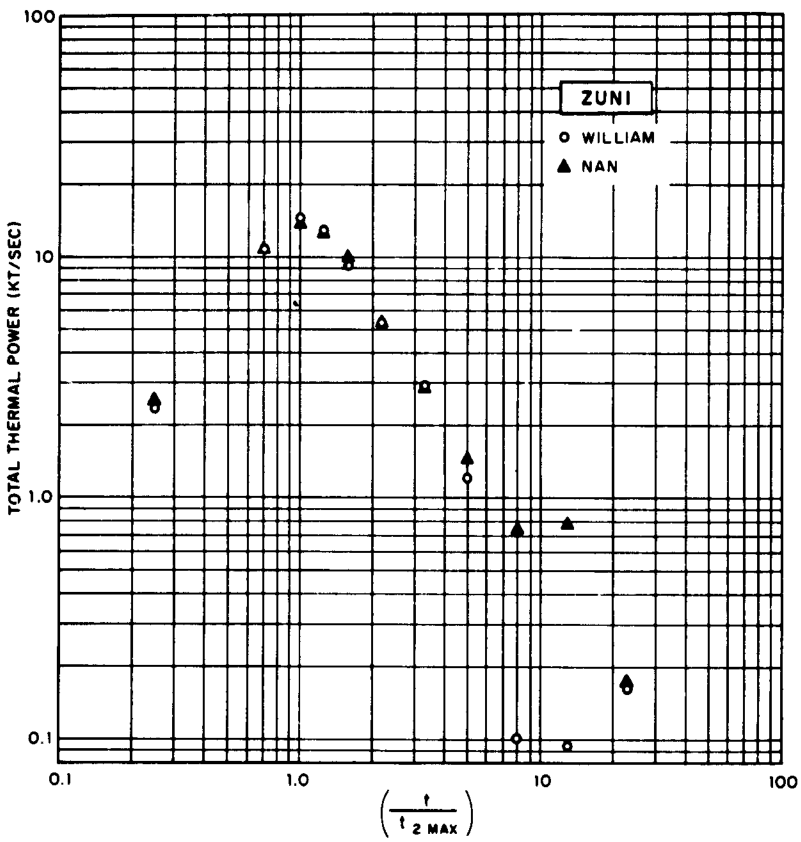

Figure 4.3 Total thermal power versus time, Shot Zuni.

Ψ, and the color temperature of the fireball determined from the observed values. The formula used in computing the expected ratio is

$$R(\Psi)_{n,\,m} = \frac{\int_\lambda J_\lambda(\Psi)\tau_\lambda(\Psi)f_{\lambda,\,n}d\lambda}{\int_\lambda J_\lambda(\Psi)\tau_\lambda(\Psi)f_{\lambda,\,m}d\lambda} \tag{4.3}$$

Where: $J_\lambda(\Psi)$ = the spectral intensity of black-body source of temperature, Ψ, at the wave length, λ

$\tau_\lambda(\Psi)$ = the estimated transmission of the atmosphere at wave length, λ, for a black-body source of temperature, Ψ

$f_{\lambda,\,m}$ = the transmission of filter m at wave length λ

$f_{\lambda,\,n}$ = the transmission of filter n at wave length λ

The estimated color and power temperature for each station and shot are given in Figures 4.4 through 4.11.

The authors were unable to complete an analysis of the field-of-view data due to the large drop error for Shot Cherokee, the excessive obscuration at Site Yvonne during Shot Lacrosse and at Site Nan during Shot Zuni, and the present lack of polar scattering information suitable for treatment of EPG-type atmospheres.

4.1 SHOT LACROSSE

Since this detonation was the first and only kiloton-range surface burst on which thermal measurements were made and analyzed, there are no criteria by which to judge the accuracy or reasonableness of the interpretation presented in the previous section.

It is interesting to note that the thermal yields, power temperatures, and color tempera-

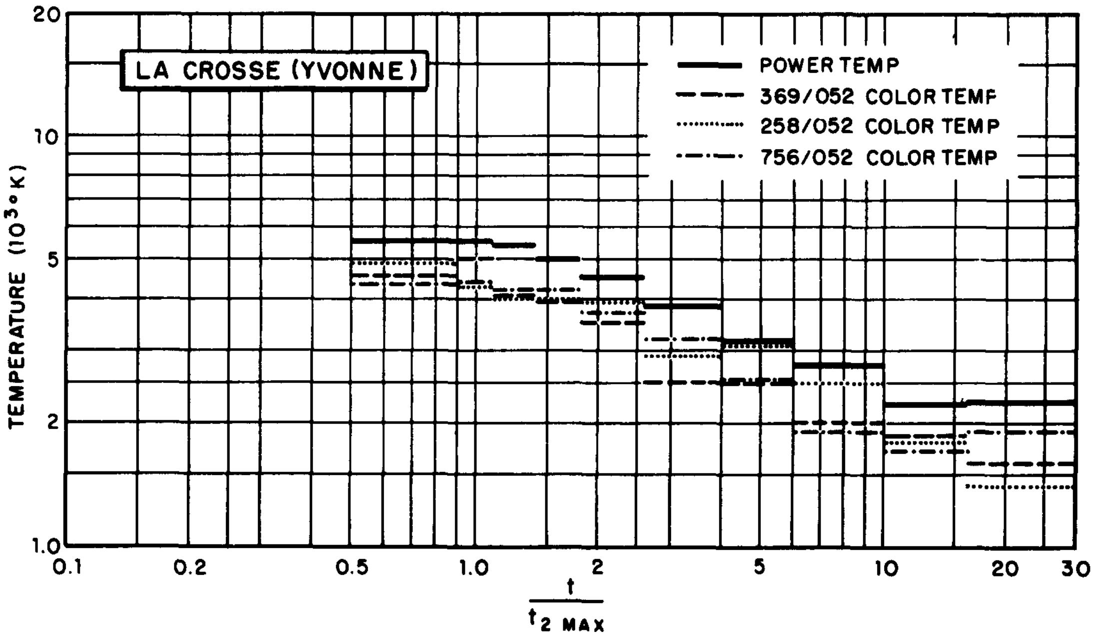

Figure 4.4 Temperature versus time, Shot Lacrosse, Site Yvonne.

tures, as interpreted by the authors, are different when determined from opposite sides of the fireball. The differences seem too great to be explained in terms of atmospheric attenuation or obscuration external to the fireball.

It is of interest to speculate on the possibilities of an asymmetric fireball. Since the power and color temperatures seem to be essentially the same at each station, it is possible that the Site Yvonne side of the fireball was actually colder than the Site Wilma side. The reported asymmetric shock wave (Reference 4), asymmetric fireball shape (Reference 5), the difference in temperatures shown by the unpublished preliminary analysis of the Air Force Cambridge Research Center (AFCRC) spectral data, and the unpublished preliminary analysis of the thermal measurements from aircraft all tend to lend credibility to this possibility. A possible cause of such a phenomenon might be the extensive experimental apparatus extending from the device cab on the Site Yvonne side.

4.2 SHOT CHEROKEE

Shot Cherokee has been the only multimegaton, low-altitude air burst, and there are no

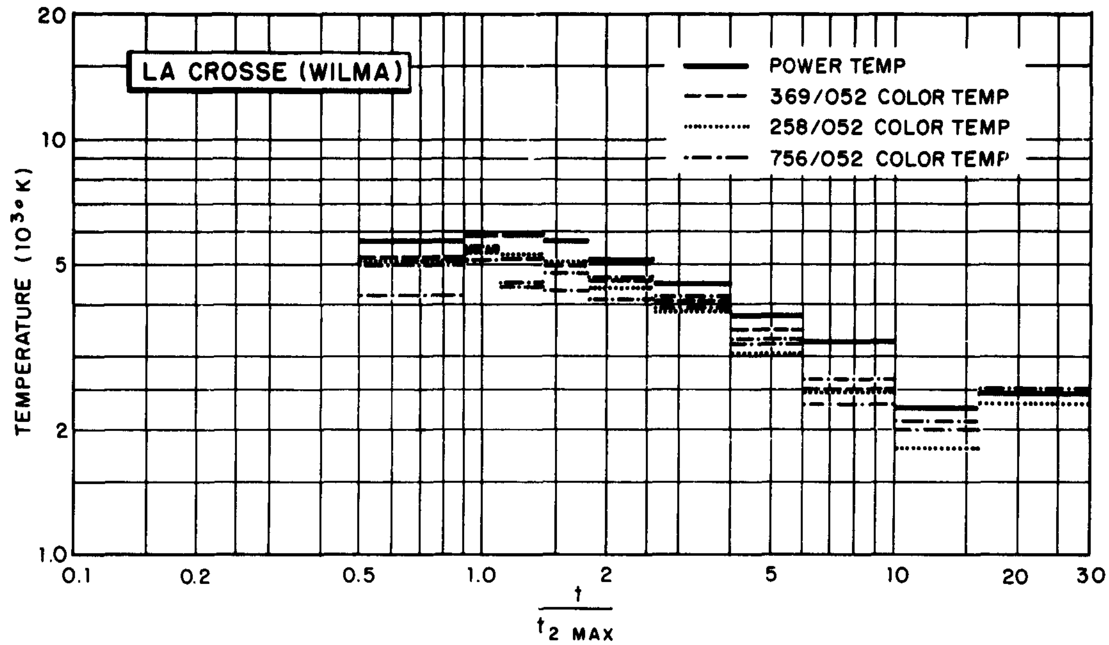

Figure 4.5 Temperature versus time, Shot Lacrosse, Site Wilma.

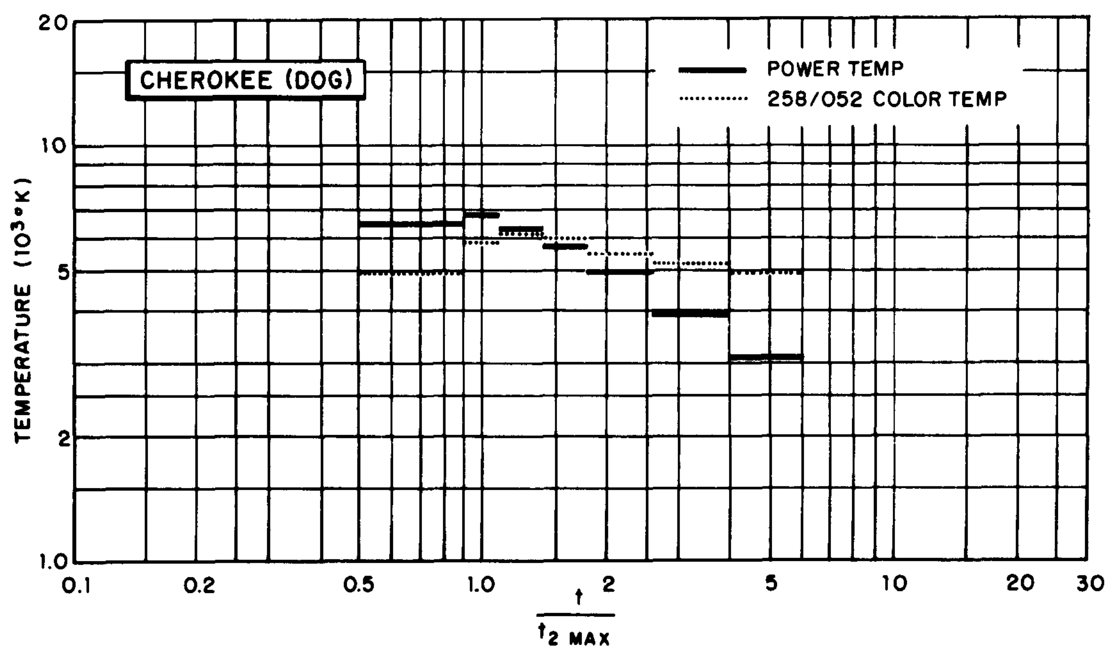

Figure 4.6 Temperature versus time, Shot Cherokee, Site Dog.

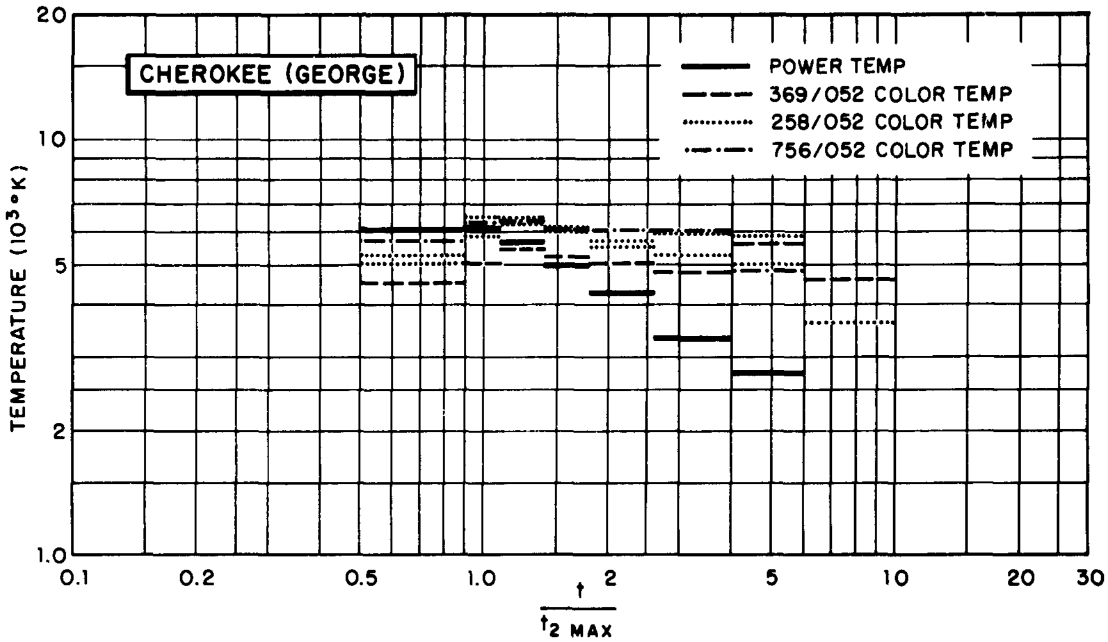

Figure 4.7 Temperature versus time, Shot Cherokee, Site George.

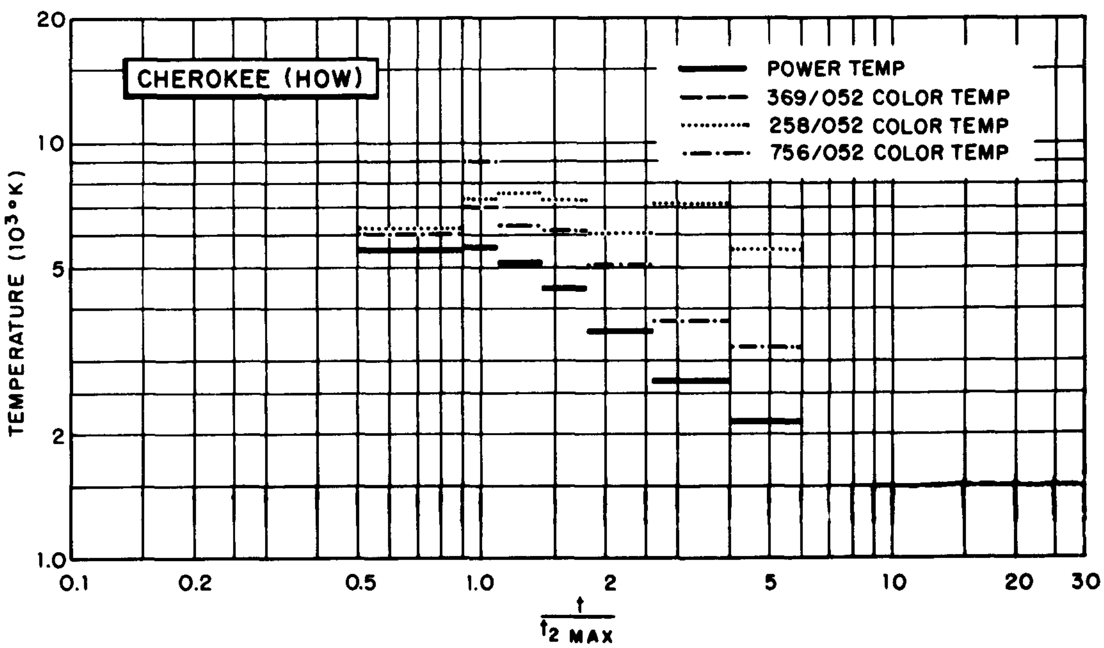

Figure 4.8 Temperature versus time, Shot Cherokee, Site How.

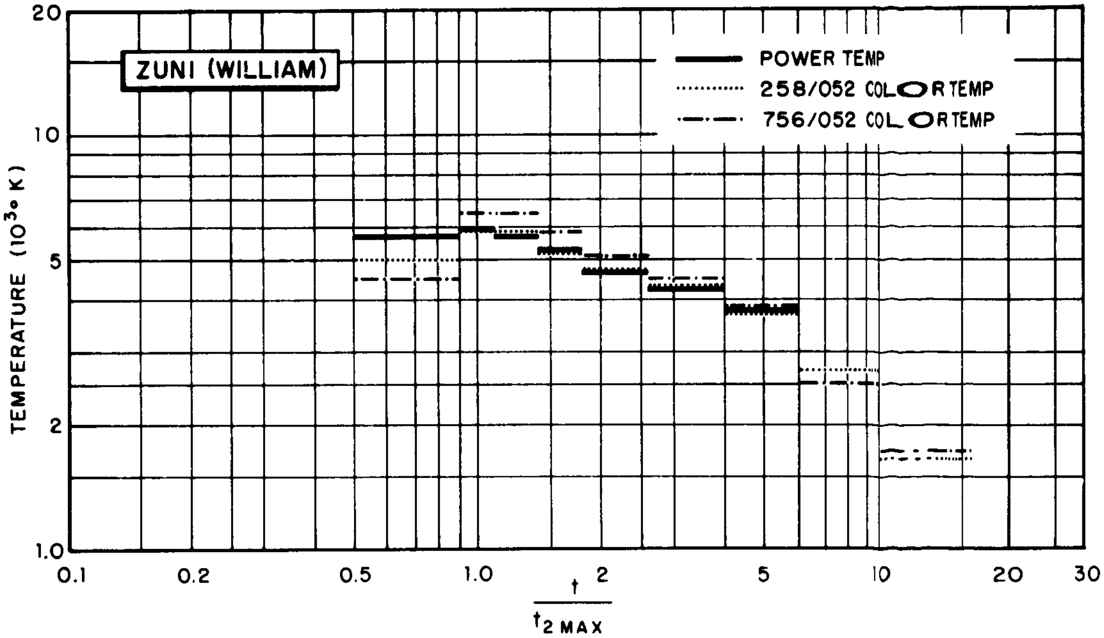

Figure 4.9 Temperature versus time, Shot Zuni, Site William.

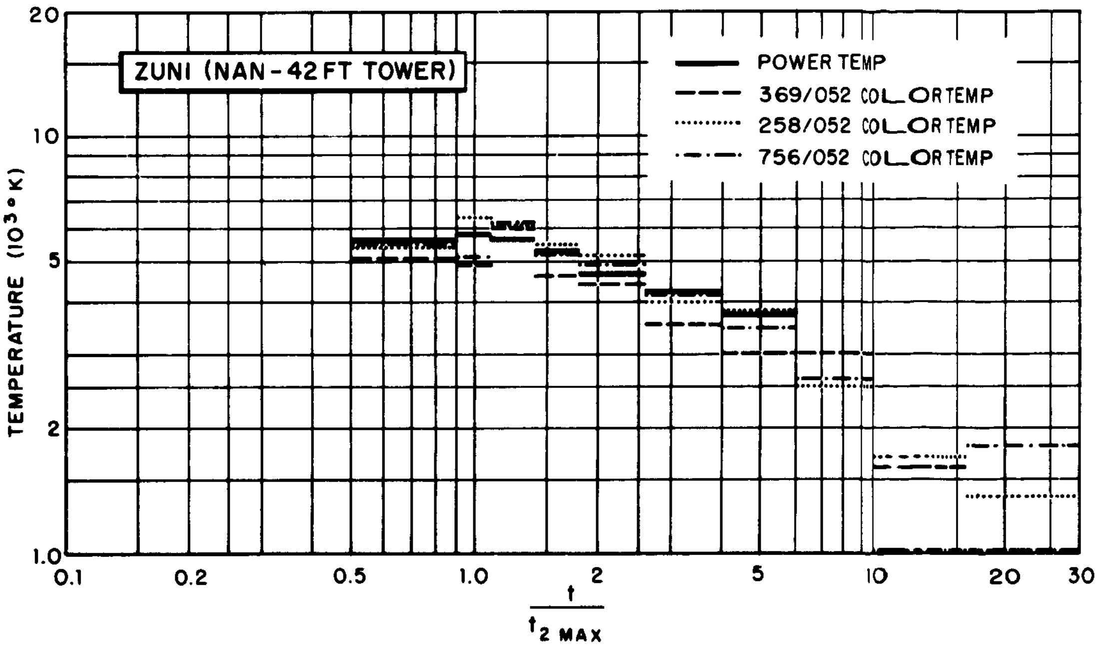

Figure 4.10 Temperature versus time, Shot Zuni, Site Nan, 42-foot tower.

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criteria for assessing the accuracy or reasonableness of the results. The lack of fireball photography taken from the locations of thermal measurements, due to the large drop error, makes determination of the cloud obscuration impossible and the thermal yield analysis uncertain. No reasonable method of computing atmospheric attenuation known to the authors will result in a unique value of thermal yield, even though the internal consistency of the thermal measurements at each station is considered excellent. Since the probability of cloud reflection increasing a measured value is low, the thermal partition of Shot Cherokee is probably greater

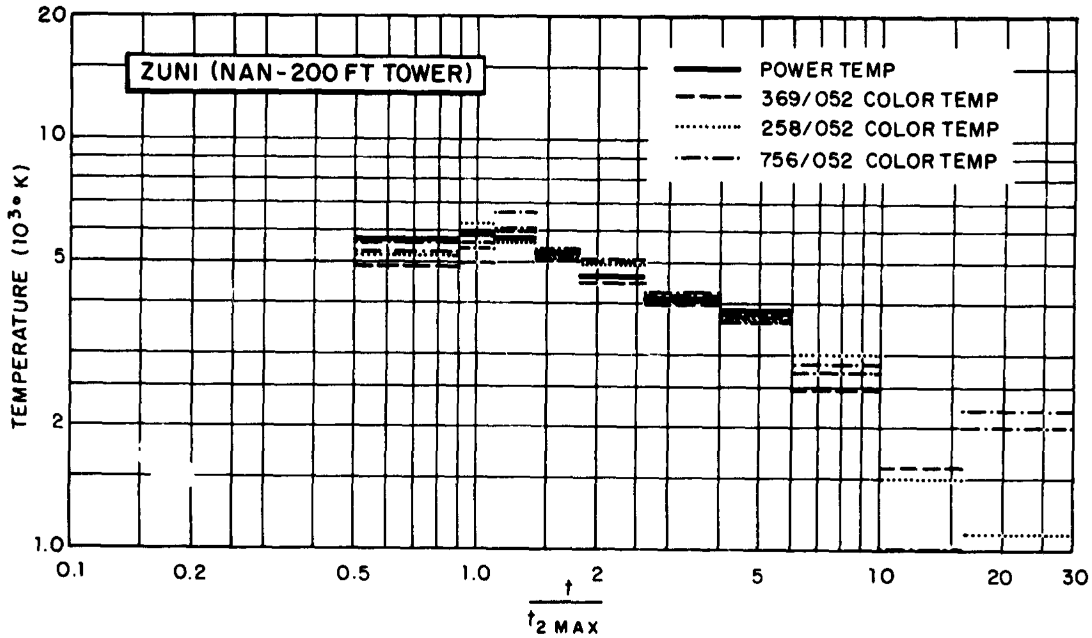

Figure 4.11 Temperature versus time, Shot Zuni, Site Nan, 200-foot tower.

than 30 percent. On the basis of the power and color-temperature results, it is also reasonable to conclude that the peak temperature was probably in excess of 6,000 K.

An interesting feature of Shot Cherokee is the apparent variation of the time to second maximum as a function of the azimuth of the observer. The data from the ground stations reported herein and the unpublished data from a P2V aircraft, all of which were taken from an easterly direction from the device, indicate a time to second maximum of about 1.5 seconds. The unpublished data from an F-84 aircraft south of the fireball indicates a second maximum of about 1.7 seconds. Unpublished data from the B-52 and B-47 aircraft west of the fireball indicate a time to second maximum of about 2.0 seconds.

4.3 SHOT ZUNI

The Shot Zuni measurements were the first observations of a surface burst from the ground. The estimated value of the thermal yield, as determined from Site William, is about the anticipated value. The thermal yield from Site Nan is higher, but is subject to larger uncertainty because of excessive obscuration due to clouds and smoke.

4.4 SCALING LAWS

Meaningful scaling of thermal yields and effective fireball temperatures for surface bursts cannot be undertaken on the basis of the measurements reported herein, because of the limited number of bursts, difficulties of interpretation, and apparent differences in results between the two stations on each shot. The scaling of surface burst fireball radii are also premature due to the limited number of observations and the asymmetry reported for Shot Lacrosse (Reference 5).

Most of the scaling information for Shot Cherokee was lost, due to the large drop error and the excessive cloud coverage. The size of the fireball was determined from two independent sources, and it was found that air-burst-fireball radii scale about as the 0.37 power of the total yield.

The time to second maximum for Shot Cherokee seems open to question. It is interesting to note that if the times to second maximum of all air bursts detonated between 3,000 and 5,000 feet mean sea level altitude are plotted (on log-log scales) as a function of yield, the 1.5-second value gives an excellent fit, the second maximum scaling as about the 0.42 power of the total yield. The only air bursts in this altitude range that do not fit a $0.045\ W^{0.42}$ time-to-second-maximum scaling law would then be Shots 1 and 2 of Operation Tumbler-Snapper. A time to second maximum of 2.0 seconds for Shot Cherokee appears to fit a scaling law, including all tower, surface, and air bursts at low altitude for which thermal measurements have been reported.

The delay of a time to second maximum can be explained by the phenomenon of burning away of clouds, which is often observed on bursts detonated at the EPG.

Chapter 5
CONCLUSIONS and RECOMMENDATIONS

5.1 CONCLUSIONS

Thermal measurements for a 40-kt surface burst, a 3.8-Mt air burst, and a 3.5-Mt surface burst proved successful from an instrumental point of view, but the interpretation of the results is uncertain, due to a lack of sufficient atmospheric attenuation data, excessive obscuration at several of the stations, and the large drop error of the air burst. At the two locations from which surface-burst measurements were made without excessive obscuration, the values of thermal yield, as estimated by the authors, compare favorably with the W/7 values that were anticipated. In the opinion of the authors, however, scaling laws for surface bursts should be derived on the basis of these limited results.

These surface-burst measurements and the tower-burst measurements made during Operation Teapot (Reference 3) indicate an apparent decrease in thermal output and in effective fireball temperatures when there is material other than air present in the fireball. This phenomenon will be investigated further as additional thermal analyses are completed for other field tests.

On the basis of the limited results to date, the scaling of surface bursts appears to be different from the scaling for air bursts. The time to second maximum for surface bursts appears to scale about as $W^{0.5}$, whereas the second maximum for air bursts appears to scale more closely to $W^{0.42}$. The scaling of thermal yields for surface bursts is not well established, but it appears to be different from the $W^{0.95}$ scaling that has been observed for air bursts at low altitudes. The scaling of fireball radius has not yet been fully investigated, pending the receipt of data from other surface bursts.

5.2 RECOMMENDATIONS

It is recommended that a high priority be given to the measurement of the thermal characteristics of a megaton-range air burst at about 5,000 feet of altitude in a relatively cloud-free atmosphere. The importance of the characteristics of such a burst cannot be overemphasized from scaling and energy-prediction standpoints. With the exception of Shot King, Operation Ivy, for which usable thermal measurements were not made, the largest air burst for which data are available is a 60-kt device. This requires an extrapolation by a factor of about 100 in yield to predict the safety of pilots delivering megaton-range air burst. While the highest value of estimated thermal yield for Shot Cherokee is about W/3, the authors are not in a position to guarantee that this value is not in error by as much as 50 percent. In addition, if further surface bursts in the kiloton range are planned, it is recommended that thermal measurements from ground stations be made for these tests. Data from aircraft stations will probably be sufficient to determine the thermal characteristics of megaton-range surface bursts.

If further thermal measurements are attempted, it is recommended that the method used to measure color temperature be modified so as to give more-accurate results with less laborious reduction of data. Similarly, the field-of-view measurements should be modified to give more-accurate and more-applicable results. Atmospheric-attenuation measurements, applicable to EPG-type atmospheres, are an essential requirement for the interpretation of thermal data. It is recommended that suitable measurements be completed at the earliest possible date.

The data taken to date on field tests, up to and including Operation Redwing, show great promise of yielding a theory for predicting the thermal characteristics of nuclear detonations. Acceptance of the above recommendations may well substantiate the current theory and enable thermal predictions to be made accurately enough for military operational use.

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